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SPACE CONSTRUCTION SYSTEM ANALYSIS

PART 2 FINAL REPORT
SPACE CONSTRUCTION EXPERIMENTS CONCEPTS

APRIL 1980

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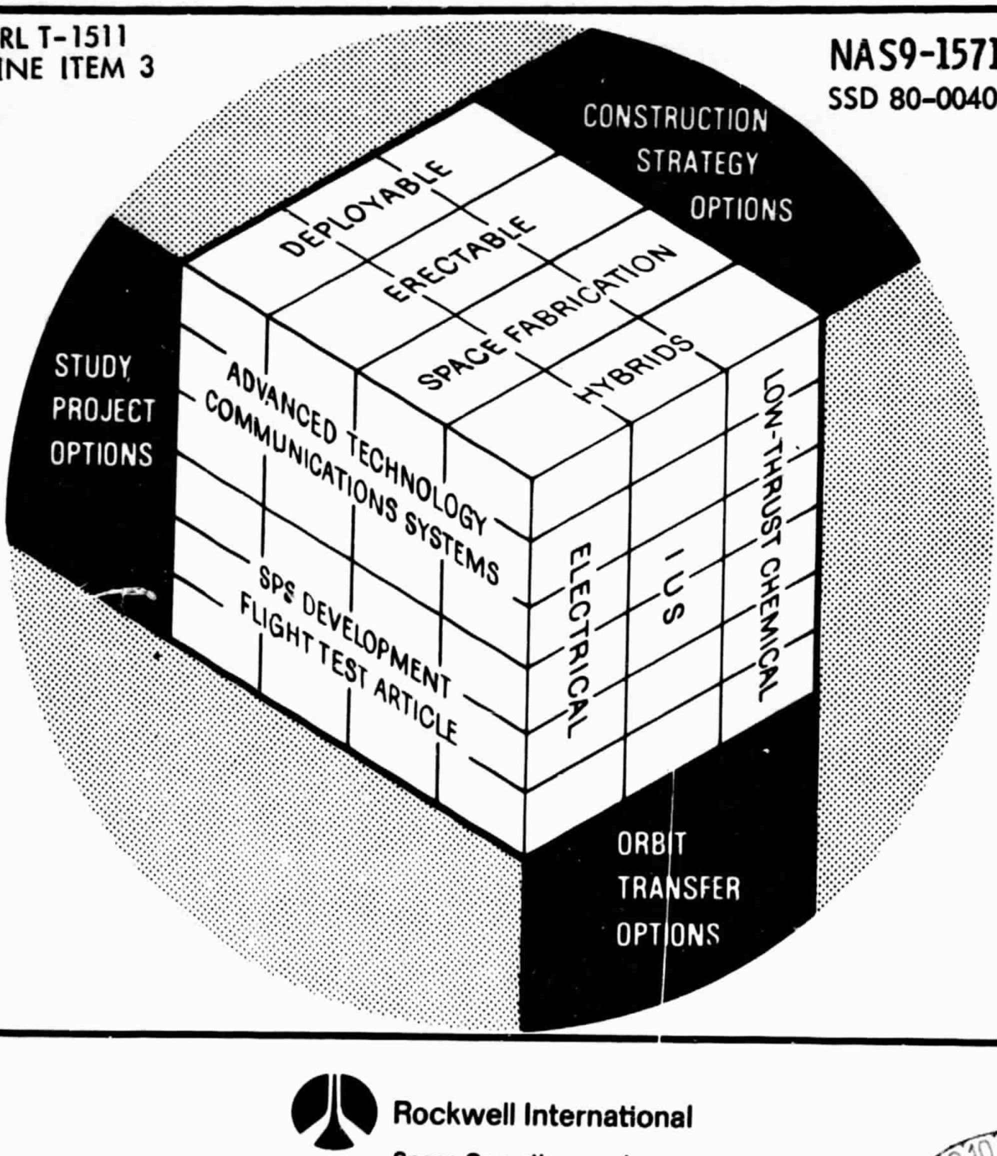

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SSD 80-0040

SPACE CONSTRUCTION SYSTEM ANALYSIS
FINAL REPORT

Space Construction Experiments Concepts

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FOREWORD

This report summarizes the Space Construction Experiments Concepts, Task 13, of the Space Construction Systems Analysis Study. Various space experiments for early Shuttle orbiter missions were defined and their respective operational sequence and mission timelines evaluated. Each experiment test objective was devoted to verifying and space-qualifying technology that is directly pertinent to space construction of large structures. This contract effort was conducted by the Space Operations and Satellite Systems Division, Space Systems Group, of Rockwell International Corporation for the National Aeronautics and Space Administration, Johnson Space Center. The work was administered under the technical direction of the Contracting Officer's Representative (COR), Mr. Lyle Jenkins, Spacecraft Design Division, Johnson Space Center.

The study was performed under the direction of Lowell F. Wiley, Study Manager, Task 13. The following persons made significant contributions toward completion of the analyses reported herein:

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Space Construction System Analysis, Part 2, Platform Definition, Final Report — SSD 80-0037

Space Construction System Analysis, Part 2, Construction Analysis, Final Report — SSD 80-0038

Space Construction System Analysis, Part 2, Cost and Programmatics, Final Report — SSD 80-0039

Space Construction System Analysis, Final Report, Space Construction Experiments Concepts — SSD 80-0040

Space Construction System Analysis, Part 2, Executive Summary Final Report — SSD 80-0041

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1.0 INTRODUCTION

This report documents Task 13 of the Space Construction System Analysis Study Part II. Task 13 is a Space Construction Experiment Concept Study.

NASA has contracted studies for a variety of space systems which in their operational configuration will exceed the dimensions of the orbiter cargo bay. These systems are deployable, space erectable, and/or space fabricated out of the orbiter cargo bay. Many of the techniques required are proven techniques not requiring space validation, however, there are many processes, techniques, and procedures required that are new and require space validation prior to commiting them to common use. Much can be done with ground simulations, ground testing, and analysis, however, space test confirmation is necessary. Well planned experiments on early orbiter flights will provide the basis for development of accurate operations planning with a better base for timeline estimates as well as correlation with analysis and ground simulations. Construction dynamic interaction with the orbiter dynamics and control also require further understanding and verification by experiment.

The objective of Task 13 is to define three or more concepts for Space Construction Experiments that provide data for Space Construction related functions where ground testing and analysis techniques are inadequate.

An appendix has been included containing the results of a precision deployable boom experiment analysis study activity that was completed at the close of the Space Construction Experiments Concept Study. This experiment is important in that it identifies the characteristics for a large space construction payload experiment that is companion to the large space construction platform experiments. The precision deployable boom experiment involves a 100-meter mast which presents a test medium for testing advanced control techniques for structure shaping and vibration mode control. The configuration also presents the opportunity to probe the limits of orbiter control authority and to evaluate orbiter/construction interaction effects.

The following sections define the study flow, the task results, and conclude with a concept definition for each of four experiments. The concept definition is in the form of experiment drawings, mission scenarios, and design and operations requirements.

2.0 STUDY FLOW

The assembly of large space structures in-orbit requires advances in several technology areas. These areas include structures, remotely operated assembly techniques and, control and stabilization. There must be a systematic program of technology development and flight test in large space structures which will lower the technological risk to a point of user acceptance.

The objective of this study was to define several experimental concepts for simple space construction experiments which provide an initial step towards the development of some anticipated large space system.

The experiment concepts as defined by Rockwell International and discussed herein will provide the initial cornerstone experiments in a building block approach for a continuous on-going technology development program.

The design philosophy adopted for each experiment concept is to address generic classes of problems associated with realistic advanced concepts rather than individual user specific items. The benefits derived from each experiment concept will provide technology relevant to, but not dependent on, potential user's needs. The experiments shall develop correlation data between the flight tests and ground test and analyses for construction functions. Such functions include orbiter operations, lighting, TV, RMS handling techniques, control system integration, and modes and damping of the experiment structure.

Figure 2-1 presents the task study logic. The overall approach adopted was to review numerous advanced large space structures design concepts proposed by the aerospace community and identify their construction procedures and requirements. Information on technology requirements was collected from available published sources.

The initial Task 13.1 effort was the development of experiment selection criteria and candidate experiment listings. This activity drew heavily on the data generated in Part 1 of the Space Construction System Analysis Study and other pertinent studies.

The experiment selection criteria were used to evaluate the relative worth of various design concepts developed in Task 13.3. In addition, the selection criteria were used by Rockwell early in the study to screen candidate experiments (Task 13.2) resulting in the recommendation of four experiments for further study. The selection criteria include considerations of:

- Legacy - addresses verification of construction issues for anticipated large space systems.
- Space Verification - versus ground verification capability.

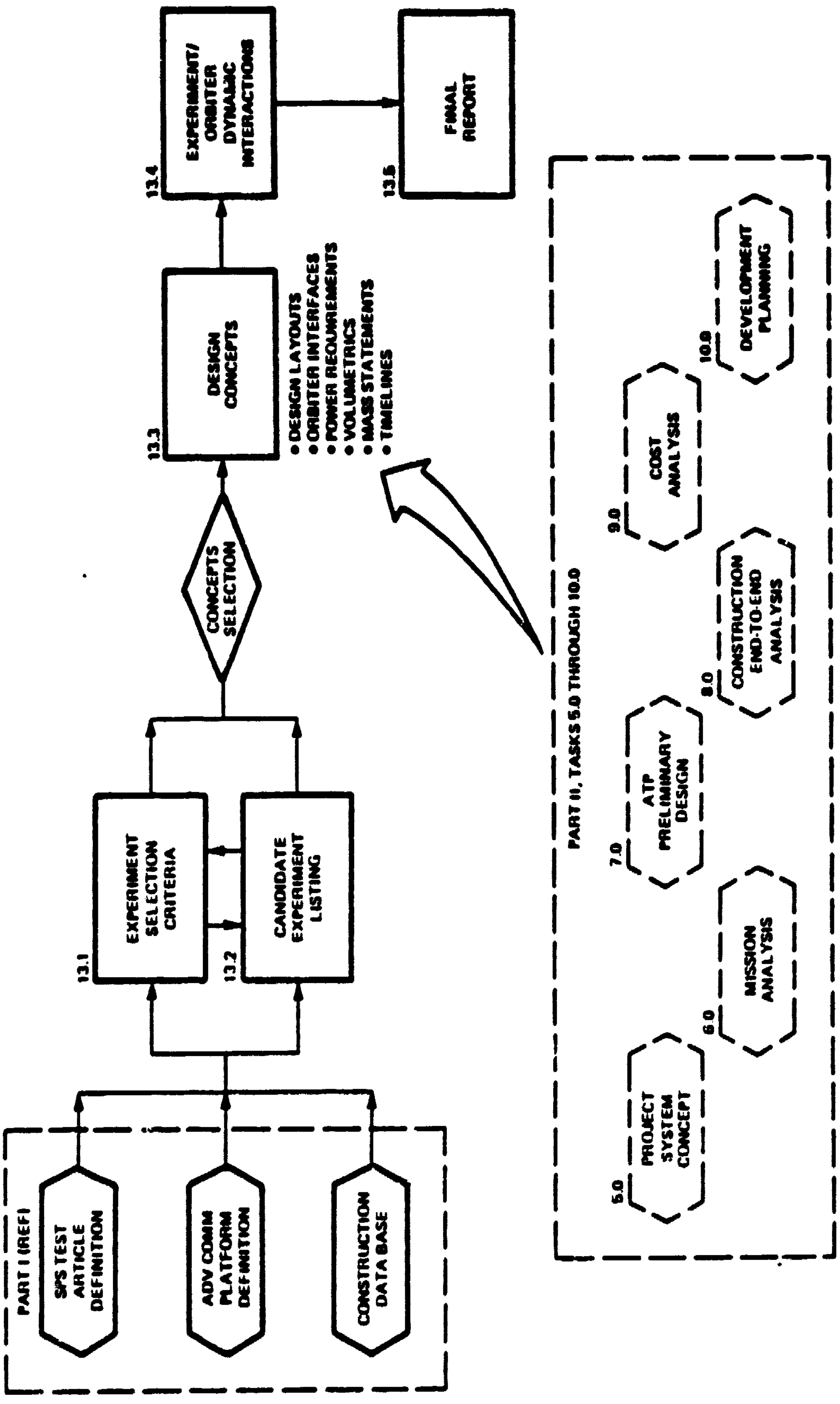


Figure 2-1. Task 13 Study Logic

- Technology Criticality - a driver for large space system development.

- Bring Back - capability to retrieve and return for inspection, future use, or ground evaluation.

- Relative Cost - qualitative comparison with other experiments.

Task 13.2 was concerned with generating a listing of candidate experiments and their respective experiment objectives. The listing, with brief descriptions, relied heavily on a technology review of the construction functions defined during Part I of the Space Construction System Analysis Study and data from an associated NASA contract on "Advanced Technology Requirements for Large Space Structures".

The experiment descriptions defined the technology issues to be addressed in sufficient depth to allow a meaningful assessment of the candidate experiment to be made in terms of the selection criteria developed in Task 13.1. This subtask resulted in the recommendation of four experiments for further study.

The objectives of design concepts Task 13.3 was to develop conceptual designs for the four experiments selected in Task 13.2. These conceptual designs included:

- Experiment objectives
- Design layouts
- Orbiter interface definitions
- Power requirements
- Volumetrics (cargo packaging requirements)
- Mass statements
- Comparative experiment timelines

Much of the data generated by Tasks 5.0 through 10.0 of Part II of the Space Construction System Analysis Study was made available during the design concept phase of this task. These data were reviewed to assure that the design concepts incorporated the latest thinking regarding construction of large space systems.

Each of the proposed design concepts was required to address classes of technology development problems that would be pertinent to realistic advanced concepts involving large space structures. The experiment design concepts were developed within the framework of the following criteria and ground rules.

1. The experiment was sized to be easily installed in the orbiter.

2. The experiment is compatible with early orbiter missions.

3. The experiment is compatible with orbiter equipment and capabilities.

4. The RMS and EVA shall be incorporated in varying degrees in different experiment concepts.

5. The PIDA (Payload Installation and Deployment Aid) or its major component developed at JSC, was incorporated in some of the concepts.

6. The experiment will not be flown free of orbiter.

7. The experiment definition will be useful to some anticipated large space structures.

Task 13.4 (Experiment/Orbiter Dynamic Interaction) investigated the effects of the experiment concepts to determine requirements, concepts, and issues associated with orbiter control and dynamic interactions during the space construction experiment intervals. In some cases, particular orbiter maneuvers or control actions may be required as parts of the experiments; in other cases, orbiter control systems may be inhibited to preclude unacceptable interactions with the experiments.

The two most promising experiment concepts were described in detail and the test fixtures and strut modules were fabricated as 1/5-scale models. These models, together with models of the orbiter (cargo bay), cherry picker, manned maneuvering unit, RMS and astronaut will be provided as study end items. The collection of models will be capable of demonstrating the major on-orbit operational sequences of the experiments.

3.0 CANDIDATE EXPERIMENT OBJECTIVE

The overall study approach adopted was to review numerous advanced large space structures design concepts proposed by the aerospace community and identify their construction procedures and requirements. The advanced concepts range from large flexible antennas to systems having long flexible solar arrays. They included systems which were erectable, deployable, or fabricated in orbit or any combination thereof. All of the space constructed concepts studied rely to a certain degree on technology which at best is ground-tested, and to advanced technology which is in concept form, far from being fully understood and space qualified.

Information on technology requirements associated with advanced space construction concepts was collected from various available published sources. In particular data from, and personnel intimately familiar with, the two NASA contracts of "Advanced Technology Requirements for Large Space Structures" and "Space Construction Analysis Study" were used in developing and evaluating the relevant utility of a listing of space experiment objectives. Figure 3-1 shows the process of identifying the various technology needs for space construction. These needs can be categorized in the following five basic areas:

- Assembly Procedures
- Construction Aids
- Control Systems
- Structural Elements
- Payload Packaging and Deployment

Technology need is defined as (1) the need to develop a technology that does not currently exist, and/or (2) the need to develop the technology and acquire operational data associated with the technology before the design of the operational LSS system can proceed.

Many of the technology needs are peculiar to one of the above specific areas while others will embrace more than one area. Each subject can be further subdivided; for example, the Assembly Procedures considered Construction Aids Capability, Orbiter/Platform Motion, Assembly Operations, and Assembly Performance. Each area will tend to have technology needs dealing with the same class of problems. The needs associated with Orbiter/Platform Motion for example are concerned with the relative motions of flexible bodies and their dynamic interaction as shown in Figure 3-2. Many of these technology needs identified for large space erectable structure in reference 3.1 are directly relatable to other types of structures including deployable and space fabricated concepts.

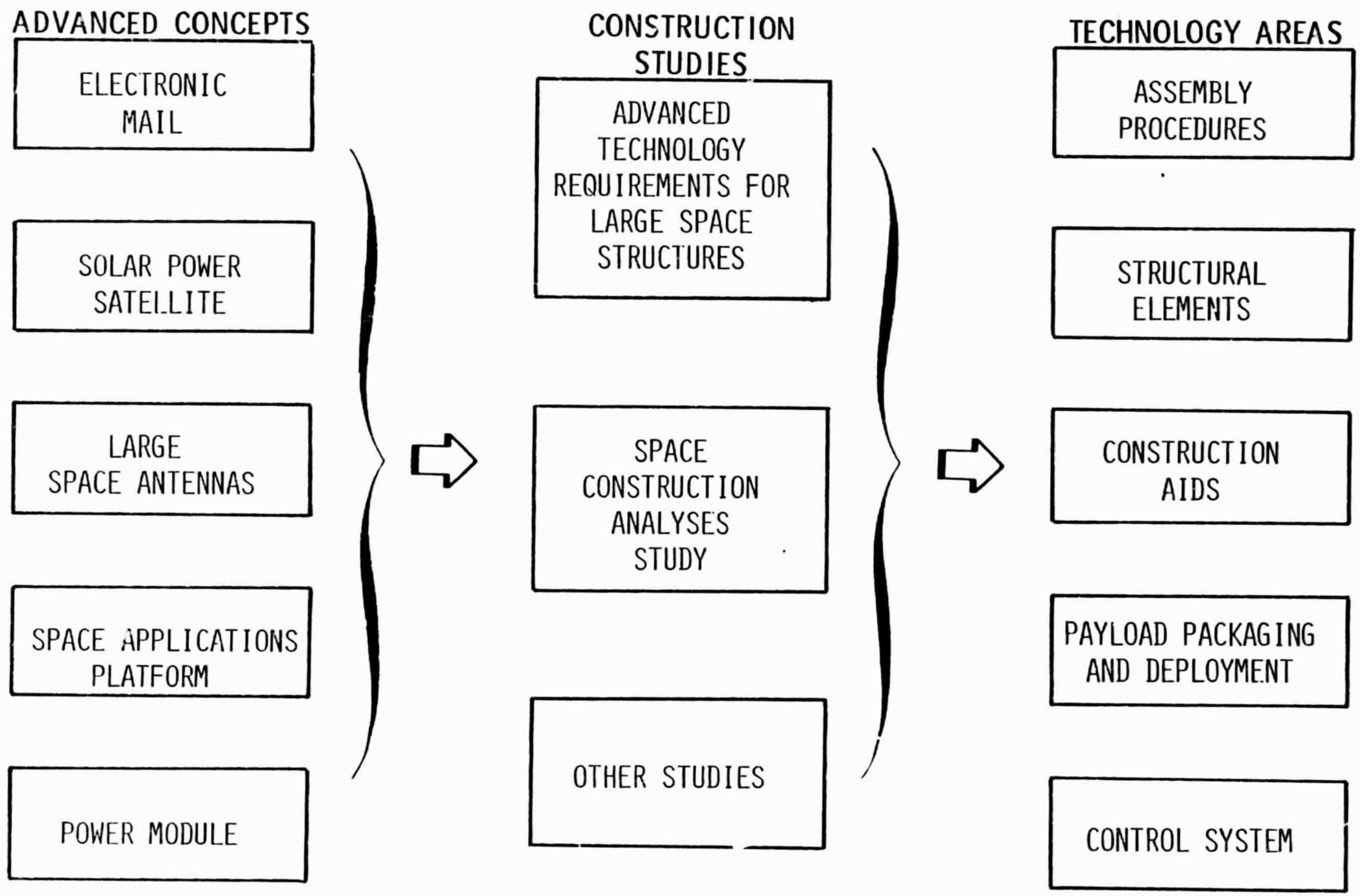


Figure 3-1. Identification of Technology Needs for Space Construction

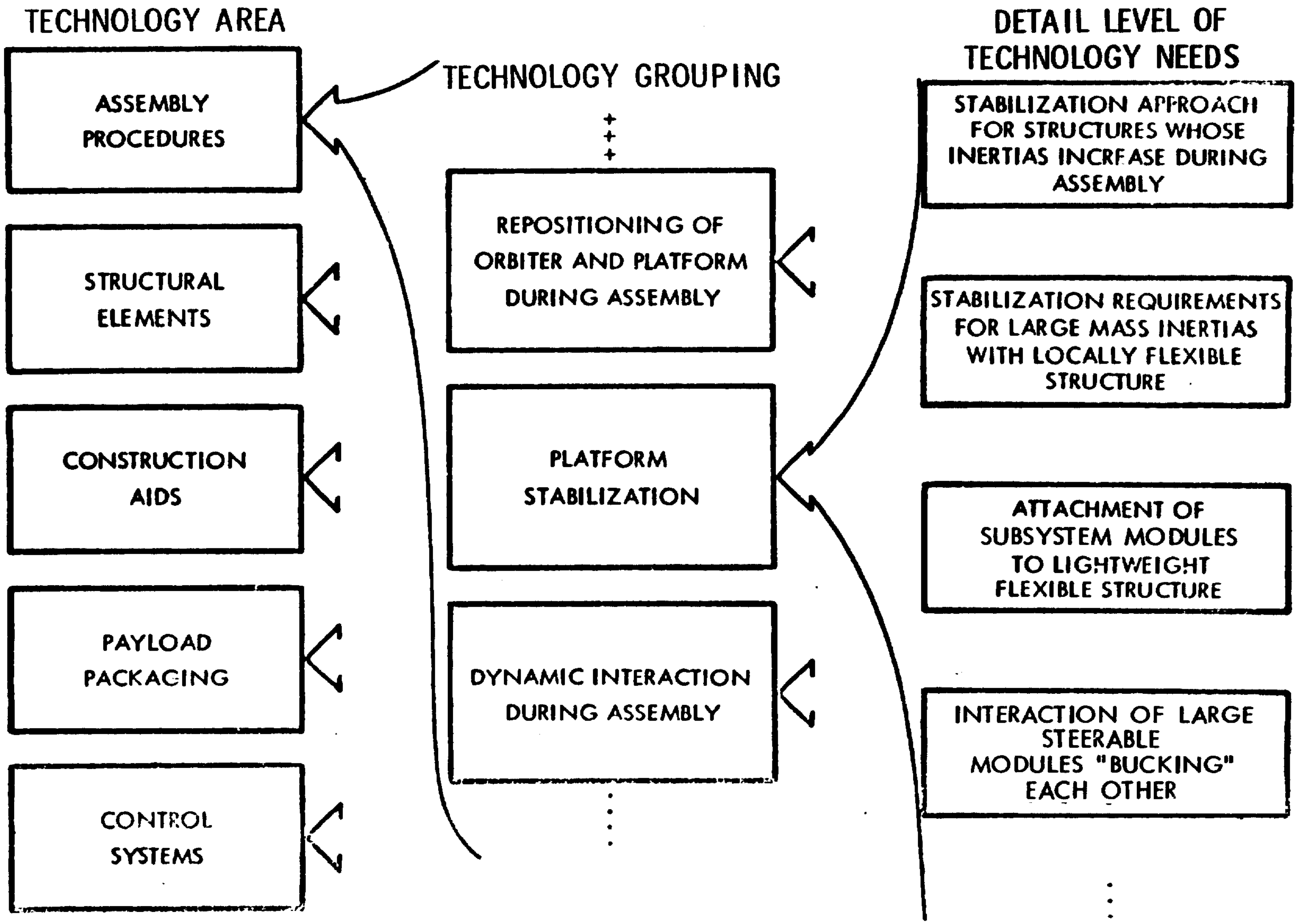


Figure 3-2. Technology Needs for Space Construction

ASSEMBLY PROCEDURES

The on-orbit assembly procedures suggested for LSS construction are predicated on the feasibility of untried operations and using "paper" designs of untested equipment. The areas of technology needs can be broken down into the following major groupings of concern:

Assembly Operations

- Adjustment and Alignment
- Mission equipment/subsystem installation
- Element and sub-module joining - welding, union/struts, etc.
- Tensioning - bracing wires, membranes
- Surface contour verification/sensor measurement

Orbiter/Platform Motion

- Docking of LSS to Orbiter
- Dynamic interaction between orbiter and construction
- Maneuvering structure between module installation stations
- Stabilization of assembly

Assembly Performance

- Crew effectivity
- Manned vs. automation
- Remote viewing - direct
- Visibility sun glint/eclipse shadow
- Parallel vs. serial operations

Each of these sub-areas are concerned with several assembly operational elements. For example, the Adjustment and Alignment area is concerned with the final closure and on-orbit adjustment of multi-point attachment of elements/modules/sub-assemblies. These problems will include:

- Maximum force permissible in making closeout due to improper alignment caused by manufacturing, assembly, and thermal tolerances and distortions
- Effect of thermal gradient on element (strut/beam/module) deflection and extension/contraction which will magnify the elements length tolerance and require adjustment to allow joining without excessive force
- Element length adjustment using the RMS effector while at the same time holding the element; amount of adjustment has to be determined prior to adjustment
- Determination of correct element length after adjustment in order to effect joint without a forced fit
- Locking of adjustment after installation

The term "element" is meant to include struts, beams, secondary structure, end fittings, etc.

The success of the assembly procedure will depend upon the speed of operation and the man/machine interaction. Information is available on a limited amount of on-orbit assembly operations, involving mostly EVA activities.

The effectiveness of the crew in operating remotely various type construction aids has to be successfully demonstrated under space conditions. A measure of their effectiveness has to be verified for the extended mission duration and with the heavy duty cycle required for the long work shifts. Experiments need to be designed to measure the crew's assembly productivity rate, which includes:

- Concentrated effort for long work shifts (up to 6 hours)
- Complex operations of precise motion of end effectors for final closing and assembly procedures
- Repetition of operational sequence on crew fatigue and boredom
- Handling of emergency operations as they manifest themselves
- Speed of operation commensurate with degree of accuracy

The assembly procedures will be accomplished at some distance from the operators as well as next to the orbiter's bay. For the installation procedures, the maximum remote distance can approach 30 m from the operator. It remains to be determined whether:

- Remote viewing is adequate for precision positioning of effectors
- 3-D depth perception can be achieved with either a single or stereo TV camera RMS mounted
- Operator's response reaction timing to remote viewing display information
- Adequate discrimination of detail for final closing operations and determination of length adjustment required

These viewing operations can be further complicated by the continuously varying illumination intensity of the background and structural members. The duty-cycle requirements for the assembly operations mean that operations must be performed at any time throughout the orbit and at any orbiting orientation of the assembly when the orbiter is in a slow free-drift rate; therefore, the following information is required:

- Scene illumination intensity required to successfully discriminate small details and perform complex joining operations, both from direct viewing and remote viewing (low intensity TV camera)

- Degree of sun glinting from structural members and mean duration time of glint; since orientation is changing, does one wait for glint to disappear before proceeding with assembly operations, or use selected filters to reduce glint intensity?

- Problem of background illuminated from full sun glare of earth glow causing loss of detail at point of interest

- Degree of shadowing produced from adjacent elements affecting the scene of interest, both when natural and artificial illumination is used during the assembly

CONSTRUCTION AIDS TECHNOLOGY REQUIREMENTS

The on-orbit assembly of the LSS/platforms will require extensive use of a series of construction aids. These aids have to perform various demanding types of assembly operations and manipulations while, at the same time, the aids must be stowed within the orbiter's moldline during transportation into orbit. The construction aids have been kept to a minimum consistent with the amount of assembly and the Shuttle mission duration. A list of the foreseeable aids is as follows:

- Remote Maneuvering System (RMS)
- End Effectors/Adapters
- Module Assembly Fixtures
- Holding and Positioning Aid (HAPA)

Currently, only the RMS has been considered as standard equipment on board the orbiter; its effector has limited capability insufficient for the majority of LSS assembly operations.

All of these construction aids will be required to repeat their sequence of operations numerous times per orbiter mission. The performance endurance and degradation of these aids throughout their operational life has to be determined. The technology requirements are for a long life, intensive duty cycle, and adequate mean-time-before-failure to successfully accomplish the assembly operations.

TECHNOLOGY NEEDS ASSOCIATED WITH CONTROL SYSTEMS

A means of controlling these large highly flexible structures is required both for successful operational system performance and during the structural assembly operation. During the operational phase, the system could impose stringent surface contour requirements which necessitate advanced control concepts.

It is important to determine the specific control requirements associated with any particular mission. For some missions, the structural stiffness and disturbing forcing functions are sufficiently separated that state-of-the-art control schemes would be applicable.

The main areas of technology concern for the control system can be categorized by the following:

- System Identification
- Structural System Response
- System Modeling

Any control law has an analog model to represent the overall structure. The form and performance of any analog used has to be compared with the actual vehicle structure that it is meant to represent. The distorted shape of the structure/system has to be measured before the control system can determine the displacement error from a prescribed contour description, therefore an accurate special measuring system is required on-board. Irrespective of the form of the control law and logic, the net result will be activation of a

force control system. There are numerous means of force activation systems, but the net result is to impart concentrated forces or torques to the structure. It is necessary to understand the structural behavior of these concentrated forces on flexible members both the localized distortion and the effect on the overall surface behavior. An indication of the input data requirements and out-put responses to the control systems is depicted in Figure 3-3. These input and output effects are involved with understanding the technology associated with the control of large space structures.

The large space structures are composed of large numbers of structural elements. Any attempt to model all these elements will result in unmanageable models which are not amenable to real-time evaluation. Therefore, it is necessary to develop models adequate for the controls system description. The following needs for system modeling are:

- Simplified model of the total structure which describes the systems dynamic response; but at the same time the model can be evaluated quickly by the control system concept
- The non-linearity and irregularities in the structure have to be included in the simplified model to account for joint slop and stiction
- Methods of updating the system parameters of the simplified model depending upon the current operational state of the structural configuration

The design of the full-scale operational system will be based on predictive techniques with scale model ground and flight verification test data. It is important to progressively validate the modeling techniques from the substructure and scale models. The major technology needs pertain to:

- Substructure repeatability to a full-size platform. Test results can be obtained from small substructure and methods are needed to apply these results to the overall structure which could consist of hundreds of these substructures systematically assembled together in an organized repetitive fashion
- Removal of gravity effects on the behavior characteristics of the trusses when they are ground tested
- Representation of the joint flexibility data from ground test and predicting the effects when these joints are repeated hundreds of times to form a structural platform.
- The understanding of the ground test environment and how it influences the model test results (e.g., effects of gravity, aerodynamic damping, etc. on the dynamic behavior of the structure).

TECHNOLOGY NEEDS ASSOCIATED WITH STRUCTURAL ELEMENTS

There are three distinct groupings in the structural elements technology area: struts/beams, unions/attachment points, and bracing members/tension membranes.

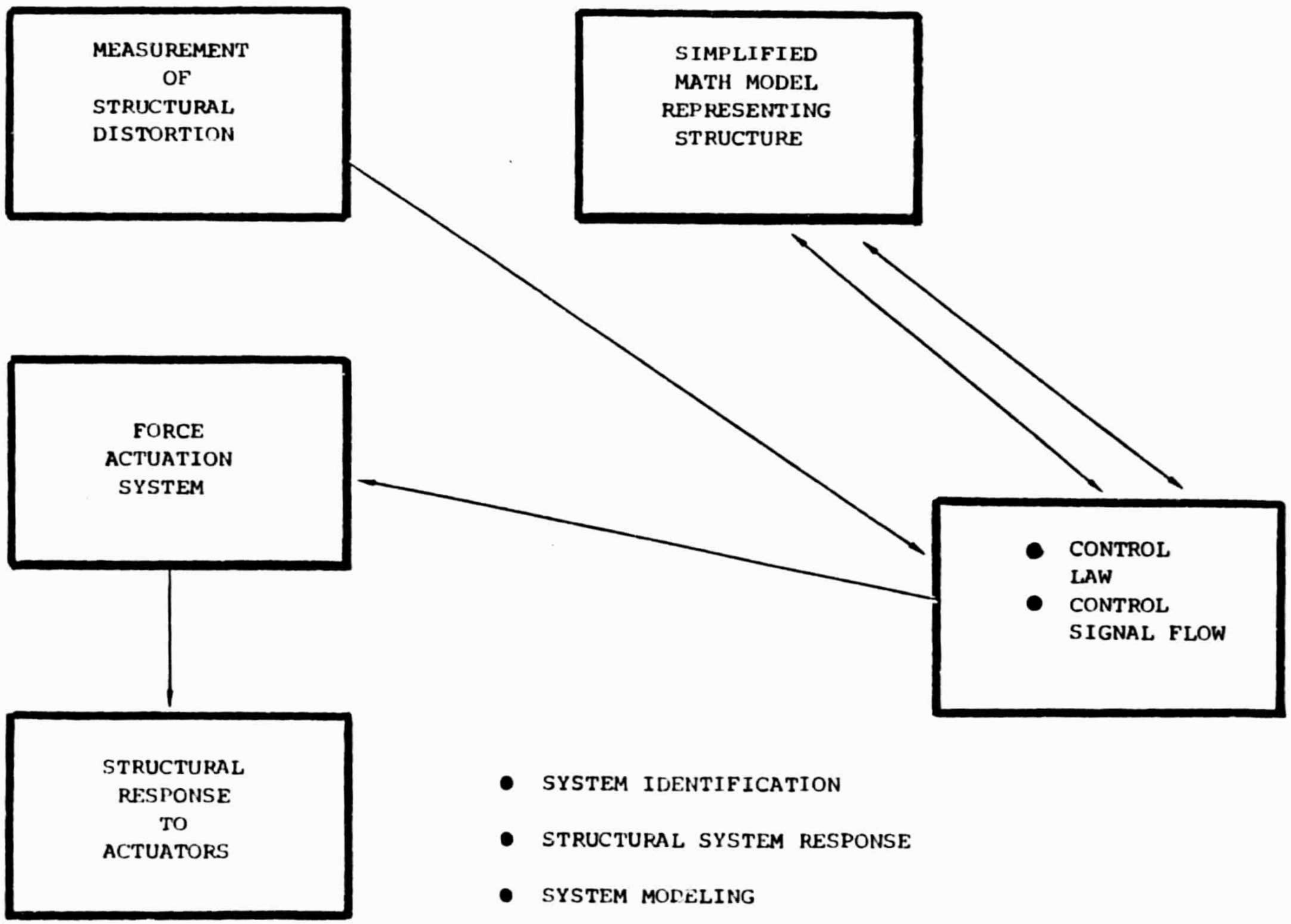


Figure 3-3. Controls and Stabilization

The class of large space structures which are assembled or fabricated in orbit is subjected to design loads resulting only from assembly loading and on-orbit operation in a zero-gravity environment. Therefore, the resulting structural design concepts are extremely lightweight and highly flexible. In fact, for extra large systems, due to the structures flexibility and magnitude of the overall size, it may be impossible to adequately ground test the operational system prior to emplacement on orbit. In particular the slenderness of the structural elements (struts) present a series of technology needs that require resolution, these being:

- Stability of long highly flexible beams/columns that might not be designed to withstand the 1-g ground environment.
- Realistic design loads criteria for the LSS. Since the on-orbit environment and operational imposed loads are relatively small, the criteria could result from careful ground handling, transportation and assembly impact loads.
- The relief afforded by the structures flexibility could significantly dampen impact loads
- Segment dimensional stability resulting in changes of element length and distortion which will affect the assembly and joining operations
- Thermal endurance of structural assembly to thermal cycling during its operational life effecting joining of dissimilar materials
- The actual degree of joint fixation and static friction that is introduced in the pin joint. Even small amounts of fixation can impose significant bending moments on the long slender struts and contribute to the damping of the dynamic motion
- Dimensional tolerances of the socket fixtures to allow assembly with varying amount of misalignment while at the same time restrict joint slop in the assembled condition
- Interface specifications on the union face that will allow easy installation and removal of equipment modules
- Dynamic behavior of the union joints in the space environment, vacuum effects on the static friction between the strut end fittings and the union socket and their contribution to structural damping

PAYLOAD PACKAGING AND DEPLOYMENT TECHNOLOGY

The lightweight structures that will be constructed in space require that the individual structural elements be efficiently packaged to take advantage of the cargo carrying capability of the Shuttle orbiter. Some of the technology associated with packaging and deployment is as follows:

- Support during boost ascent of long flexible structure composed of member segments

- Prevention of jamming of the individual elements when they are packaged together. The boost environment could impose a loading condition that could vibrate and settle the elements and interfere with their subsequent removal and deployment
- Controlled release of stored energy to fully deploy structural module
- Easy release of any form of tie-down mechanisms used in restraining the structural elements both in the cargo bay containers and from successful deployment

The many facets of technology development that are associated with large space construction will require adequate demonstration (flight and/or ground test) before they are incorporated into future design and operations of advance large space concepts. The space construction studies conducted at Rockwell International have provided insight in the general design concepts, construction details, operational procedures and the need for various types of construction equipment. Figure 3-4 shows that this information can be broken into experiment objectives that are peculiar to the structural elements of a design, and the experiment objectives relatable to space operations. Therefore a listing of 24 experiment objectives has been identified that will adequately exercise various technology requirements associated with large space construction. A correlation matrix of the basic technology area with the 24 experiment objectives is shown in Table 3-1.

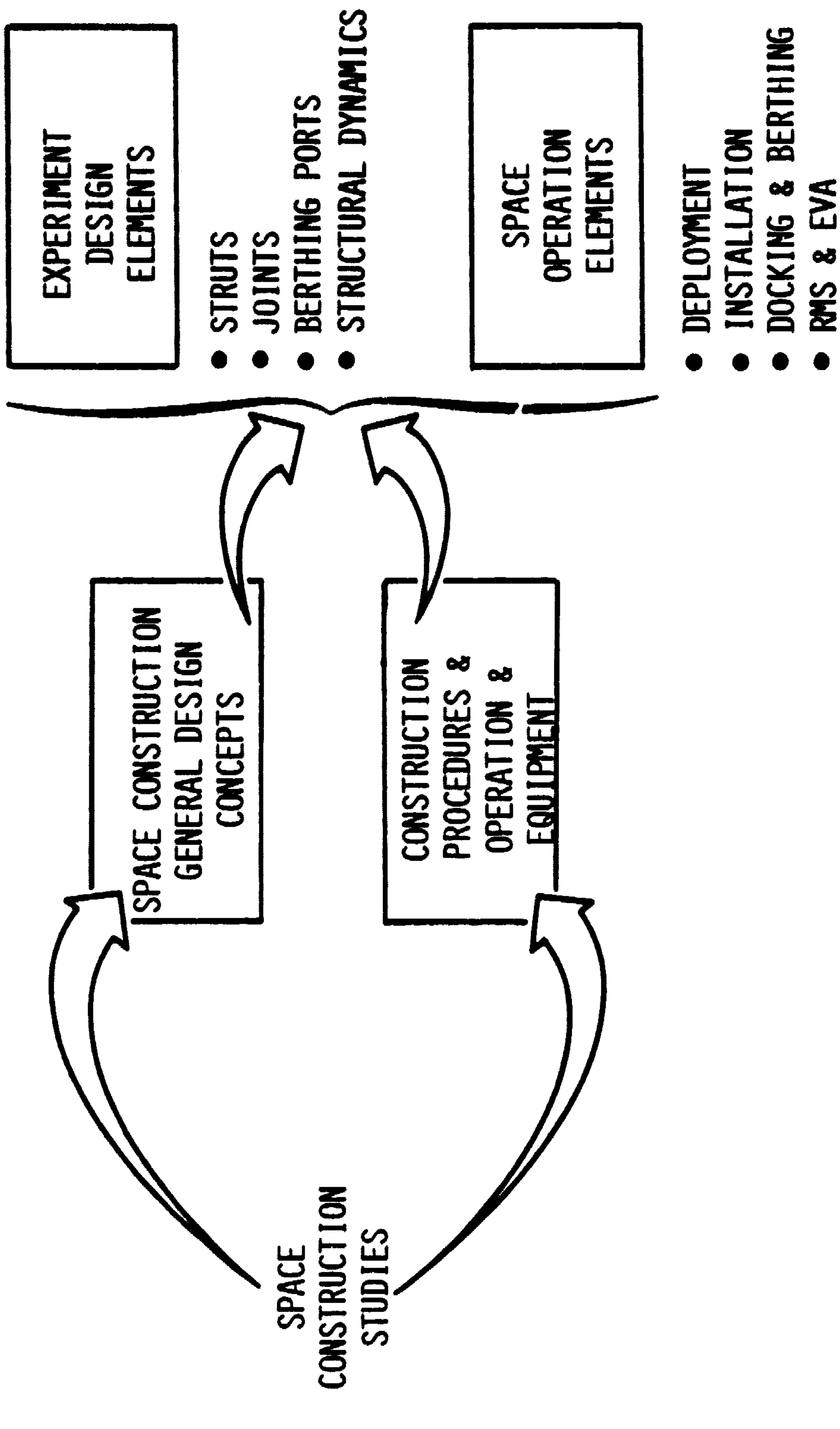


Figure 3-4. Influences on Experiment Design

Table 3-1. Correlation Matrix of Basic Technology Areas with Experiment Objectives

EXPERIMENT OBJECTIVES	ASSEMBLY PROCEDURES	STRUCTURAL ELEMENTS	CONSTRUCTION AIDS	PAYLOAD PACKAGING/ DEPLOYMENT	CONTROL SYSTEMS
1. ELECT. CABLE DISPENSING FROM CABLE REEL & ATTACH TO LONGITUDINAL BEAM	✓		✓	✓	
2. LONGERON/CROSSBEAM WIRING JUNCTION, INSTALL AND SECURE	✓	✓		✓	
3. STRUCTURAL BEAM JOINING WITH LASER INDUCTION AND RESISTANCE HEATING	✓	✓	✓		
4. DEPLOYMENT & INSTALLATION OF MODULE ATTACH PORT	✓		✓		
5. RMS MANIPULATION AND ATTACHMENT EVALUATION FOR BEAMS, STRUTS, CABLES, FITTING, LATCHES, AND TENSIONERS	✓		✓		
6. CONSTRUCTION FIXTURE DEPLOYMENT, ASSY, & ALIGNMENT (CRITICAL ASSEMBLIES)			✓	✓	
7. LOAD DISTRIBUTION, STRUCTURE DEPLOYMENT		✓		✓	
8. MMU AND CHERRY PICKER EVALUATION	✓		✓		
9. PIDA HANDOFF TO RMS END EFFECTOR			✓		
10. STRUCTURAL ALIGNMENT INSTR/TECHNIQUES		✓	✓		
11. EVA ATTACHMENT OF HARDWARE WITH RMS COOPERATION	✓		✓		
12. INSTALLATION OF LIGHT (TEMPORARY) "DRAG ON" INSTRUMENTATION TRANSDUCER AND CABLES	✓			✓	

Table 3-1. Correlation Matrix of Basic Technology Areas with Experiment Objectives (Cont.)

EXPERIMENT OBJECTIVES	ASSEMBLY PROCEDURES	STRUCTURAL ELEMENTS	CONSTRUCTION AIDS	PAYLOAD PACKAGING/ DEPLOYMENT	CONTROL SYSTEMS
13. BERTHING OF PAYLOAD TO ATTACH PORT INCLUDING ELECT. CONNECTION	✓		✓		✓
14. POSITIONING OF CROSSBEAM FOR JOINING OPERATION (EVA PARTICIPATION)	✓	✓			
15. INSTALLATION OF TENSION LINES AND ADJUSTMENT	✓				
16. ORBITER BERTHING WITH A LIBRATING TGT		✓			✓
17. ILLUMINATION/VISIBILITY, VISUAL AIDS	✓		✓		
18. INSTALLATION/TENSION MEMBRANES	✓	✓			
19. BEAM BUILDER BEAM STRAIGHTNESS	✓		✓		✓
20. ORBITER & CONSTR. INDUCED DYNAMICS	✓				✓
21. NONDESTRUCTIVE TESTS OF STRUCT. JOINTS	✓	✓			
22. ALIGN./ADJUST. TECH. AT MOD. ATTACH PORTS	✓		✓		
23. PLATFORM SERV., MOD ELEMENT, EXCHANGE LEO	✓		✓		
24. STRUCTURAL DYNAMICS	✓	✓			✓

4.0 EXPERIMENT SCREENING AND GROUPING

The purpose of the experiment screening and grouping task was to take the Experiment Objective list as defined in Table 3.1 and evaluate each objective in accord with the selection criteria. The selection criteria, when related with each objective provided a means for defining their programmatic characteristics, giving each objective further detail identity. This, then, established a foundation for a capture analysis giving identity to specific experiment groups. These groups formed the basis of definition for flight experiment concepts that satisfy the specific experiment groups.

The screening and grouping analysis is diagramatically shown in Figure 4-1.

4.1 SELECTION CRITERIA

The purpose of the subtask was to develop a set of selection criteria that could be used to define the relative worth of selected objectives and later to their assigned experiments. The selection criteria are as follows:

4.1.1 Early Mission

Is the objective suitable for early missions? Some of the considerations are size, development time, available technology, and dependency upon other developments. Funding may also get involved in this criteria.

4.1.2 Suitability for "Suit Case"

Can the objective be satisfied by an experiment configuration that is compact and that could replace another orbiter payload with a minimum response time? This also implies the experiment objective is compatible with a deployable structure, since size of cargo package is a factor.

4.1.3 Legacy

The term "legacy" defines that the objective must have application to anticipated space platform construction activities or configurations.

4.1.4 Space Verification

Is the Space Verification absolutly necessary to satisfy the objective or may ground testing be substituted? Space Verification is mainly dependent upon zero-g; however, the requirement for combined environments can be an issue.

4.1.5 Technology Critical

Is experiment that satisfies the experiment objective dependent upon new technology development? This technology criticality could be hardware-oriented or it may be operations-oriented. Operations-critical could be timeline predictions, operations methods, operations precision, or operations procedures.

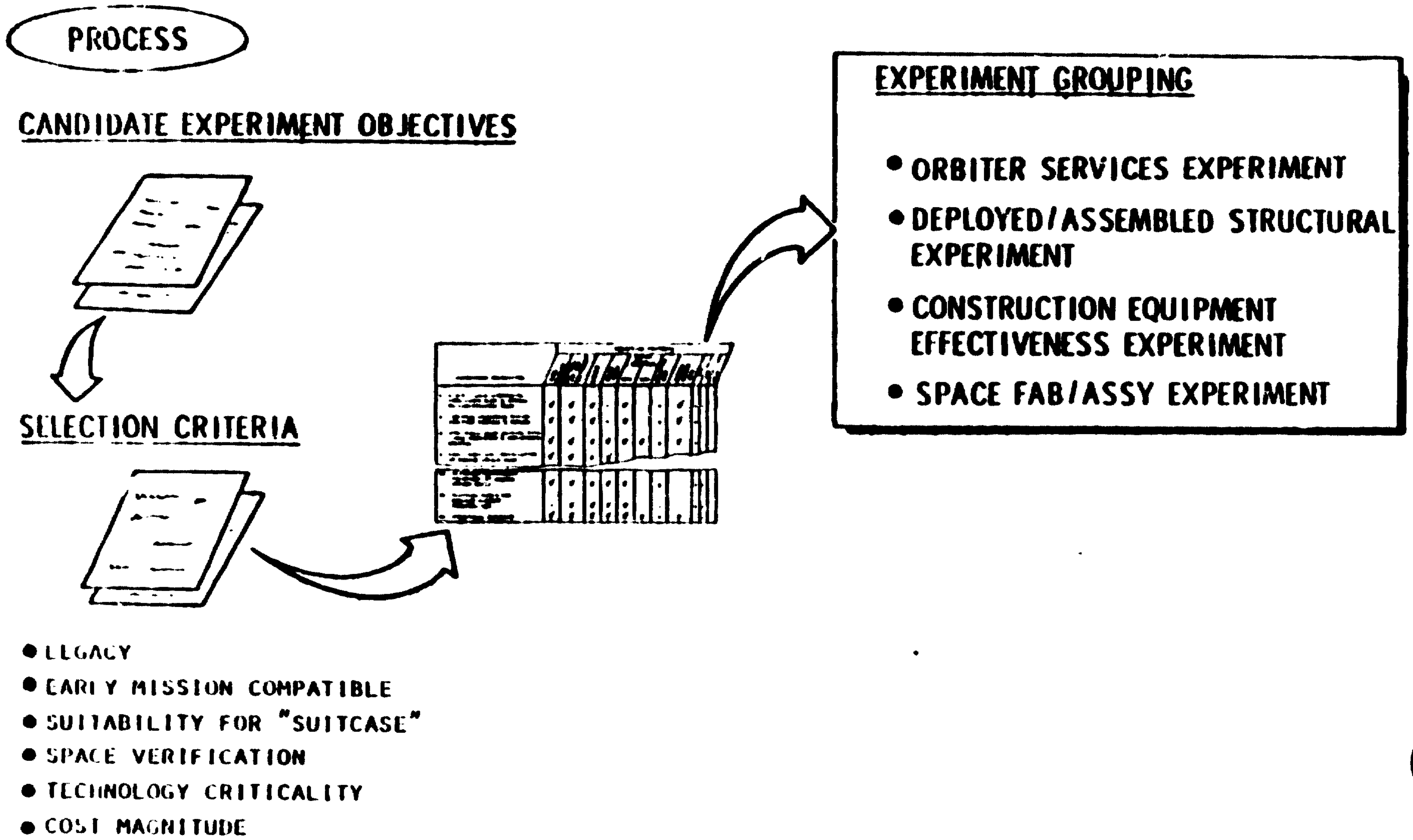


Figure 4-1. Experiment Screening and Grouping

4.1.6 Relative Cost

In the early "suit case" type experiments, cost is a factor. A study cost guideline is that the experiment should not exceed 10 million dollars. This is used as a yardstick to identify cost qualitatively by experience and judgement on a scale of 1 to 10, 10 being high cost and 1 low in cost.

4.1.7 Return/Ground Analysis

These criteria identify the dependency of the objective on a combined flight and ground test and/or required post-flight ground tests or evaluations.

4.1.8 EVA/RMS/PIDA

This selection information was included primarily to identify orbiter and crew interaction.

Collectively, the selection criteria when applied to a particular objective gives it considerable definition and provides a basis for evaluating experiment objective grouping compatibility.

The selection criteria as applied to the 24 experiments are shown in Table 4-1. These data provided the basis for grouping the experiments into experiment groups and then testing their validity by performing a capture analysis as described in the following paragraphs.

4.2 EXPERIMENT CAPTURE ANALYSIS

Four basic experiment groups were identified by carefully examining the 24 flight objectives. These groups are shown in Figure 4-1 and are as follows:

Group I	Orbiter Services Experiment
Group II	Deployed/Assembled Structural Experiment
Group III	Construction Equipment Effectiveness Experiment
Group IV	Space Fabrication/Assembly Experiment

These experiment groups were analyzed by evaluating the experiments group by group, by examining each of the 24 flight objectives and assigning them as appropriate to each experiment group. The results of the capture analysis is shown in Table 4-2. The results show that the four experiment groups are valid and actually quite well balanced.

All objectives were captured except No. 16 (Orbiter Berthing With Librating Target) and No. 18 (Installation/Tension Membranes). Objective No. 16 may be deleted since it falls outside the study guideline of no free-flyers. Objective No. 18 would have to be devoted to a specific experiment that would have narrow application and legacy at this time; it tends to fall out of the realm of an early flight experiment.

Table 4-1. Space Construction Candidate Experiment Objectives

EXPERIMENT OBJECTIVES	SELECTION CRITERIA: EARLY MISSION	SUITABIL-ITY FOR "SUITCASE"	LEGACY	SPACE VERIF.	TECHN. CRITICAL: OPS	TECHN. CRITICAL: HDW	RELATIVE COST	RETURN/ GROUND ANAL.	EVA	RMS	PIDA
1. ELECT. CABLE DISPENSING FROM CABLE REEL & ATTACH TO LONGITUDINAL BEAM	✓	✓	✓	?	✓		5	✓	X	X	
2. LONGERON/CROSSBEAM WIRING JUNCTION INSTALL & SECURE	✓	✓	✓	?	✓		3	✓	X		
3. STRUCTURAL BEAM JOINING WITH LASER INDUCTION & RESISTANCE HEATING	✓	✓	✓	✓	✓	✓	8	✓	X		
4. DEPLOYMENT AND INSTALLATION OF MODULE ATTACH PORT	✓	✓	✓	✓			6		X	X	
5. RMS MANIPULATION AND ATTACHMENT EVALUATION FOR: • BEAMS • STRUTS • CABLES • FITTINGS • LATCHES • TENSIONERS	✓	✓	✓	✓	✓		5	✓	X	X	
6. CONSTRUCTION FIXTURE DEPLOYMENT, ASSEMBLY, AND ALIGNMENT (CRITICAL ASSYS)	?	✓	✓	✓	✓		7		X	X	

Table 4-1. Space Construction Candidate Experiment Objectives (Cont.)

EXPERIMENT OBJECTIVES	SELECTION CRITERIA										
	EARLY MISSION	SUITABIL-ITY FOR "SUITCASE"	LEGACY	SPACE VERIF.	TECHN. CRITICAL OPS	TECHN. CRITICAL HDW	RELATIVE COST	RETURN/GROUND ANAL.	EVA	RMS	PIDA
7. LOAD DISTRIBUTION STRUCTURE DEPLOYMENT	✓	✓	✓	✓	✓	✓	8		X	X	
8. MMU AND CHERRY PICKER EVALUATION	?	✓	✓	✓	✓	✓	10+		X	X	
9. PIDA HANDOFF TO RMS END EFFECTOR	?	✓	✓	✓	✓		3			X	X
10. STRUCTURAL ALIGNMENT INSTR/TECHNIQUES	✓	✓	✓	✓	✓		4		X		
11. EVA ATTACHMENT OF HARDWARE WITH RMS COOPERATION	✓	✓	✓	✓	✓		2		X	X	
12. INSTALLATION OF LIGHT (TEMPORARY) "DRAG ON" INSTRUMENTATION TRANSDUCER AND CABLES	✓	✓	✓	✓	✓		3		X		
13. BERTHING OF PAYLOAD TO ATTACH PORT INCLUDING ELECT CONNECTION	?	✓	✓	✓	✓		9		X	X	

Table 4-1. Space Construction Candidate Experiment Objectives (Cont.)

EXPERIMENT OBJECTIVES	SELECTION CRITERIA											
	EARLY MISSION	SUITABIL-ITY FOR "SUITCASE"	LEGACY	SPACE VERIF.	TECHN. CRITICAL: OPS	TECHN. CRITICAL: HDW	RELATIVE COST	RETURN/ GROUND ANAL.	EVA		RMS	PIDA
14. POSITIONING OF CROSSBEAM FOR JOINING OPERATION (EVA PARTICIPATION)	√	√	√	√	√	√	6		X	X		
15. INSTALLATION OF TENSION LINES AND ADJUSTMENT	√	√	√	√	√		5		X	X		
16. ORBITER BERTHING WITH A LIBRATING TARGET	?	?	√	√	√		10			X		
17. ILLUMINATION/VISIBILITY VISUAL AIDS	√	√	√	√	√		4			X		
18. INSTALLATION/TENSION MEMBRANES	√	√	√	√	√		9		X	X		
19. BEAM BUILDER BEAM STRAIGHTNESS	?	?	√	√	√		10	√	X	X		
20. ORBITER AND CONSTRUCTION INDUCED DYNAMICS	√	√	√	√	√		4			X		
21. NONDESTRUCTIVE TESTS OF STRUCT. JOINTS	√	√	√	?	√			√	X	X		

Table 4-1. Space Construction Candidate Experiment Objectives (Cont.)

EXPERIMENT OBJECTIVES	SELECTION CRITERIA										
	EARLY MISSION	SUITABIL-ITY FOR "SUITCASE"	LEGACY	SPACE VERIF.	TECHN. CRITICAL OPS	TECHN. CRITICAL HDW	RELATIVE COST	RETURN/GROUND ANAL.	EVA	RMS	PIDA
22. ALIGNMENT/ADJUSTMENT TECHNIQUE AT MODULE ATTACH PORTS	✓	✓	✓	✓	✓		5		X	X	
23. PLATFORM SERVICING MODULAR ELEMENT EXCHANGE LEO	?	✓	✓	✓	✓		7		X	X	
24. STRUCTURAL DYNAMICS	✓	✓	✓	✓	✓	✓	6	✓		X	

Table 4-2. Experiment Capture Analysis

√ = OBJECTIVE NEARLY COMPLETELY EXERCISED   PA = PARTIALLY EXERCISED OBJ.

EXPERIMENT OBJECTIVES	EXPERIMENT NUMBER 1	2	3	4
1. ELECT. CABLE DISPENSING FROM CABLE REEL & ATTACH TO LONGITUDINAL BEAM	-	-	-	√
2. LONGERON/CROSSBEAM WIRING JUNCTION, INSTALL AND SECURE	-	-	PA	√
3. STRUCTURAL BEAM JOINING WITH LASER INDUCTION AND RESISTANCE HEATING	-	-	-	√
4. DEPLOYMENT & INSTALLATION OF MODULE ATTACH PORT	-	√	√	-
5. RMS MANIPULATION AND ATTACHMENT EVALUATION FOR BEAMS, STRUTS, CABLES, FITTING, LATCHES, AND TENSIONERS	√	√	PA	√
6. CONSTRUCTION FIXTURE DEPLOYMENT, ASSY, & ALIGNMENT (CRITICAL ASSEMBLIES)	-	-	PA	PA
7. LOAD DISTRIBUTION, STRUCTURE DEPLOYMENT	-	PA	-	-
8. MMU AND CHERRY PICKER EVALUATION	-	-	√	-
9. PIDA HANDOFF TO RMS END EFFECTOR	PA	-	PA	-
10. STRUCTURAL ALIGNMENT INSTR/TECHNIQUES	-	PA	-	√
11. EVA ATTACHMENT OF HARDWARE WITH RMS COOPERATION	√	√	√	PA
12. INSTALLATION OF LIGHT (TEMPORARY) "DRAG ON" INSTRUMENTATION TRANSDUCER AND CABLES	-	-	√	√
13. BERTHING OF PAYLOAD TO ATTACH PORT INCLUDING ELECT. CONNECTION	-	PA	√	-
14. POSITIONING OF CROSSBEAM FOR JOINING OPERATION (EVA PARTICIPATION)	-	-	-	√
15. INSTALLATION OF TENSION LINES AND ADJUSTMENT	-	-	-	√
16. ORBITER BERTHING WITH A LIBRATING TGT	-	-	-	-
17. ILLUMINATION/VISIBILITY, VISUAL AIDS	√	√	√	√
18. INSTALLATION/TENSION MEMBRANES	-	-	-	-
19. BEAM BUILDER BEAM STRAIGHTNESS	-	-	-	PA
20. ORBITER & CONSTR. INDUCED DYNAMICS	-	PA	-	PA
21. NONDESTRUCTIVE TESTS OF STRUCT. JOINTS	-	PA	-	√
22. ALIGN./ADJUST. TECH. AT MOD. ATTACH PORTS	-	-	-	√
23. PLATFORM SERV., MOD ELEMENT, EXCHANGE LEO	√	-	PA	PA
24. STRUCTURAL DYNAMICS	-	PA	-	PA
TOTAL OBJECTIVES EXERCISED: COMPLETELY	4	4	6	11
PARTIALLY	1	6	5	6

Upon further examination of the four experiments as defined by their flight objectives, it was revealed that the experiment described could be defined as a totality or, to a lesser degree, by backing off on the emphasis of particular objectives or reducing the number accomplished by the particular experiment. These scaled-down experiments were defined as primes of the principal experiment—for example, 2 and 2 prime, and 3 and 3 prime. This terminology and identification are used in the later sections of this report.

5.0 EXPERIMENT GROUPS

This section summarizes the four experiment groups that have been previously identified. The capture analysis described in Section 4.0 has defined the experiment group objectives. These objectives can be met with a variety of experiment designs. The concept sketches shown in Figures 5-1 through 5-4 are not meant to constrain later definition activity, but to depict the nature of the experiment as defined by the objectives.

5.1 FLIGHT EXPERIMENT GROUP I

Flight Experiment Group I, Orbiter Services Experiment, has the following assigned experiment objectives and is illustrated by Figure 5-1.

1. Evaluate RMS manipulation and attachment evaluation:
   - Beams
   - Struts
   - Cables
   - Fittings
   - Latches
   - Tensioners
2. Demonstrate EVA attachment of hardware with RMS cooperation.
3. Verify illumination/visibility visual aids.
4. Demonstrate platform servicing modular element exchange LEO.
5. Demonstrate PIDA handoff to RMS end effector.

5.2 FLIGHT EXPERIMENT GROUP II

Flight Experiment Group II, Deployed/Assembled Structural Dynamics Experiment, has the following assigned experiment objectives and is illustrated by Figure 5-2.

1. Evaluate capability of RMS for varying operations requiring precision emplacement.
2. Demonstrate structural deployment using RMS assistance for release.
3. Demonstrate mating to multi-point attachment with dimensional uncertainty.
4. Demonstrate module attachment to structural node (structural and electrical)
5. Evaluate orbiter-induced dynamics on structural deployment and construction operations.
6. Evaluate on-orbit vibration testing/random single-point transfer function and sinusoidal dwell excitation.

(1) ORBITER SERVICES EXPERIMENT

- RMS MANIPULATION & ATTACHMENT EVALUATION
  - •BEAMS •CABLES •LATCHES
  - •STRUTS •FITTINGS •TENSIONERS
- EVA ATTACHMENT OF HARDWARE WITH RMS COOPERATION
- ILLUMINATION/ VISIBILITY VISUAL AIDS
- PLATFORM SERVICING MODULAR ELEMENT EXCHANGE LEO

Δ PIDA HAND-OFF TO RMS END EFFECTOR

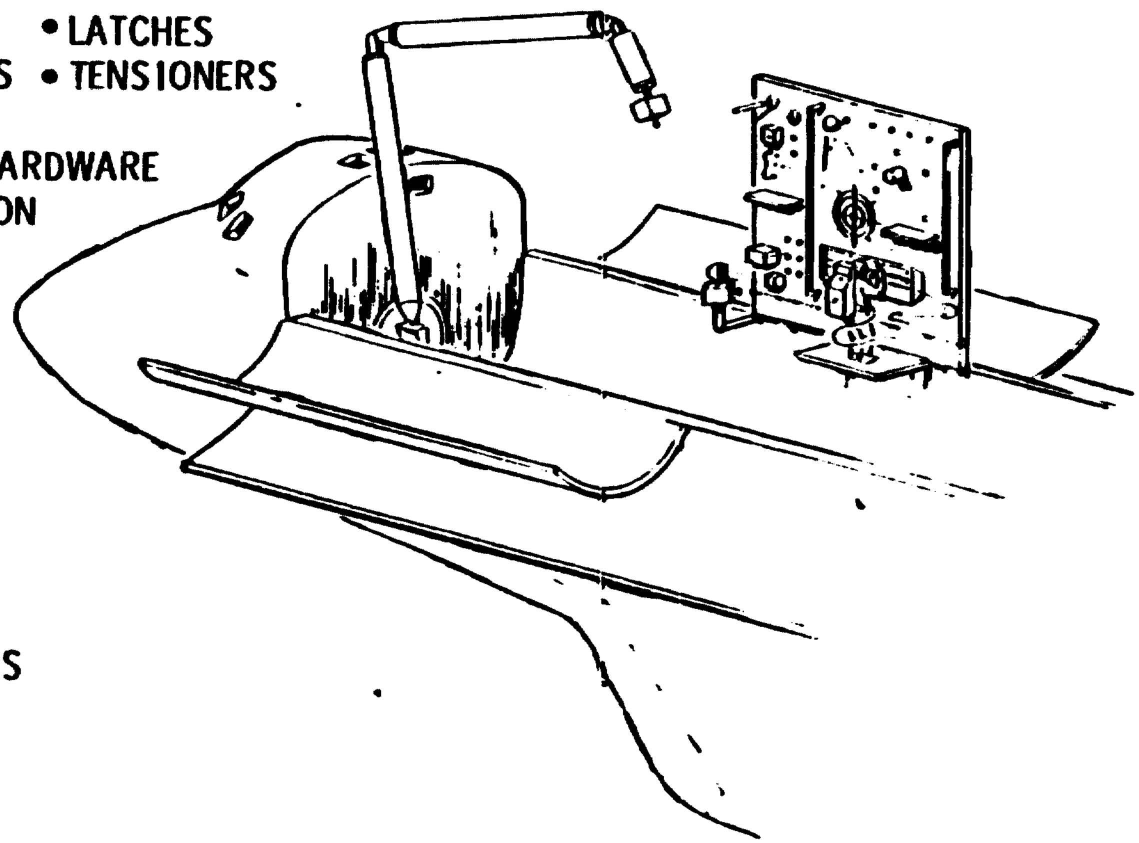


Figure 5-1. Flight Experiment - Group I

DEPLOYED/ASSEMBLED STRUCTURAL DYNAMICS EXPERIMENT

- LOAD DISTRIBUTION STRUCTURE DEPLOYMENT
- ORBITER AND CONSTRUCTION INDUCED DYNAMICS
- STRUCTURAL DYNAMICS

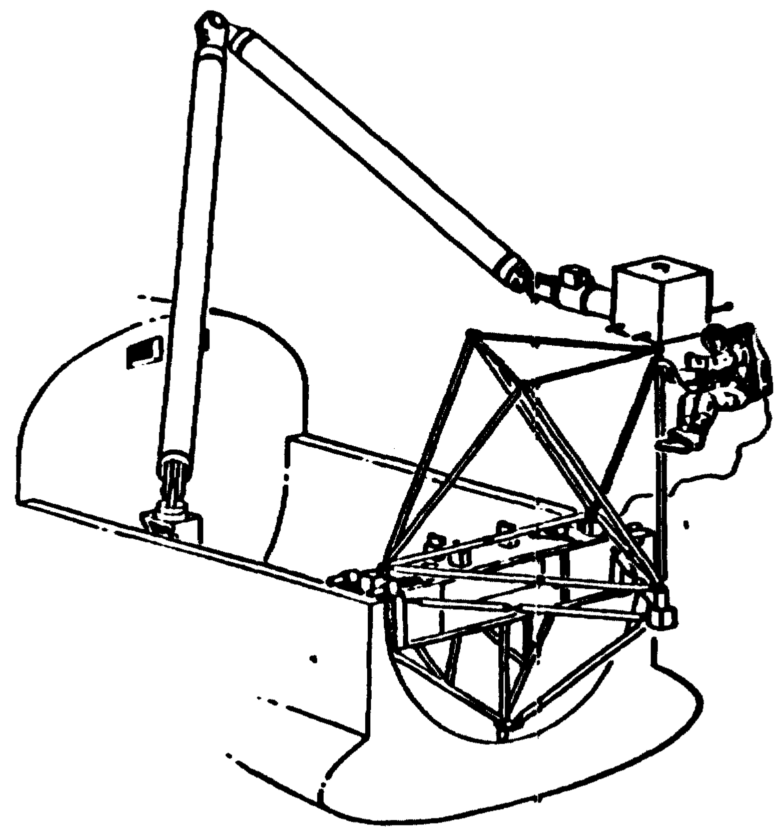


Figure 5-2. Flight Experiment - Group II

7. Evaluate vibration measurement devices for low frequency/small displacement.

8. Verify structural dynamics model, transfer function, and damping characteristics.

5.3 FLIGHT EXPERIMENT GROUP III

Flight Experiment Group III, Construction Equipment Effectiveness Experiment, has the following assigned objectives and is illustrated by Figure 5-3. The principal test objectives for this flight experiment include:

1. Evaluate operation and effectiveness of holding and positioning aid (HAPA).

2. Evaluate deployment and installation of module attach port.

3. Demonstrate berthing payload/structure to attach port, including electrical connection.

4. Evaluate EVA attachment of hardware with RMS cooperation.

5. Evaluate cherry picker support for construction operations.

6. Demonstrate installation of power/signal lines to basic structure and line connections.

5.4 FLIGHT EXPERIMENT GROUP IV

Flight Experiment Group IV, Space Fabrication/Assembly Experiment, has the following assigned objectives illustrated in Figure 5-4.

1. Demonstrate composite beam fabrication in space.

2. Verify beam alignment and tolerances.

3. Demonstrate cross-beam procurement.

4. Demonstrate cross-beam joining process.

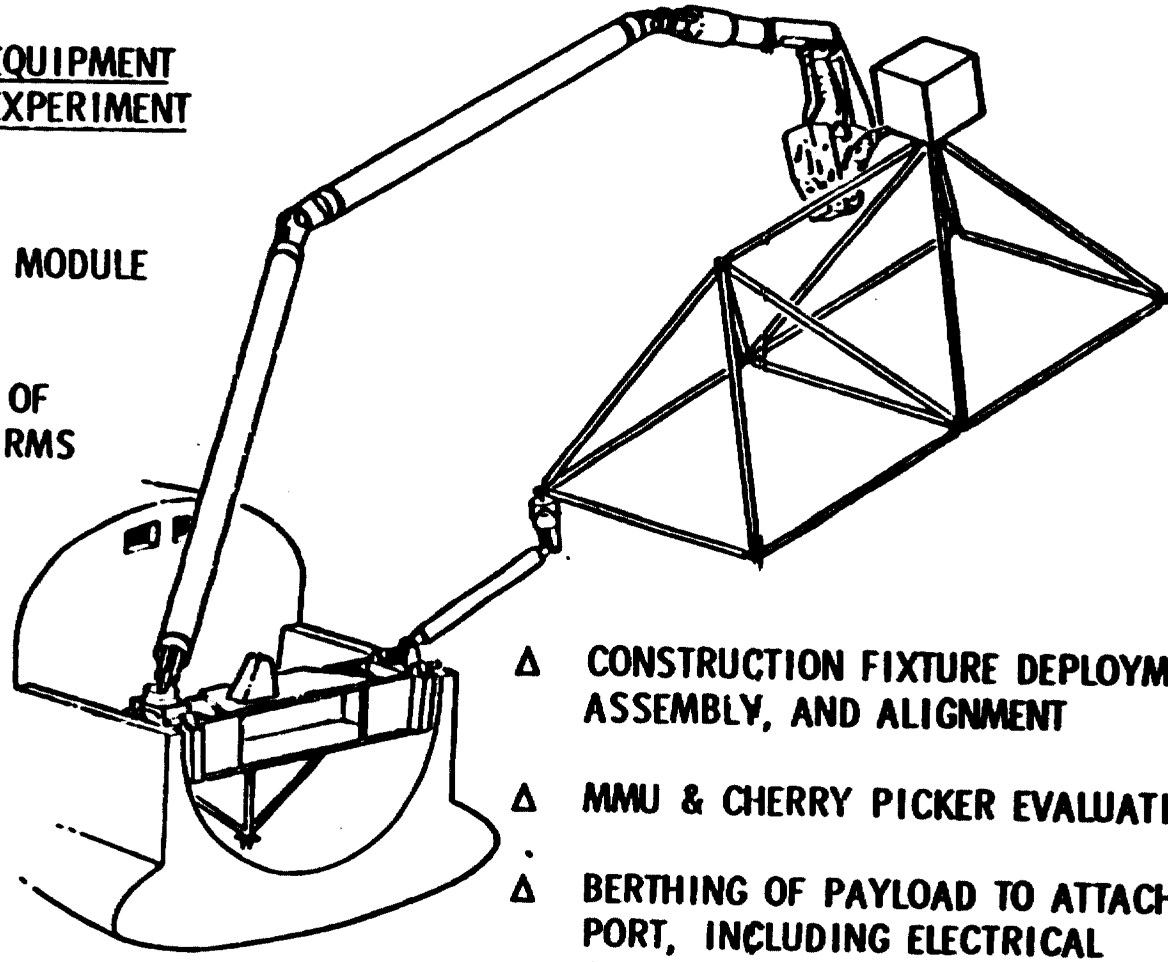
5. Verify cross-beam joint integrity.

6. Demonstrate installation of lines, cables and transducers.

7. Evaluate orbiter construction induced dynamics.

③ CONSTRUCTION EQUIPMENT EFFECTIVENESS EXPERIMENT

- DEPLOYMENT AND INSTALLATION OF MODULE ATTACH PORT
- EVA ATTACHMENT OF HARDWARE WITH RMS COOPERATION
- INSTALLATION OF LINES



- Δ CONSTRUCTION FIXTURE DEPLOYMENT, ASSEMBLY, AND ALIGNMENT
- Δ MMU & CHERRY PICKER EVALUATION
- Δ BERTHING OF PAYLOAD TO ATTACH PORT, INCLUDING ELECTRICAL CONNECTION

Figure 5-3. Flight Experiment - Group III

(4) SPACE FABRICATION/ASSEMBLY EXPERIMENT

- INSTALLATION OF LIGHT (TEMPORARY) "DRAG-ON" INSTRUMENTATION TRANSDUCERS AND CABLES
- POSITIONING OF CROSSBEAM FOR JOINING OPERATION (EVA PARTICIPATION)
- ORBITER AND CONSTRUCTION INDUCED DYNAMICS
- STRUCTURAL DYNAMICS

Δ BEAM-BUILDER BEAM STRAIGHTNESS

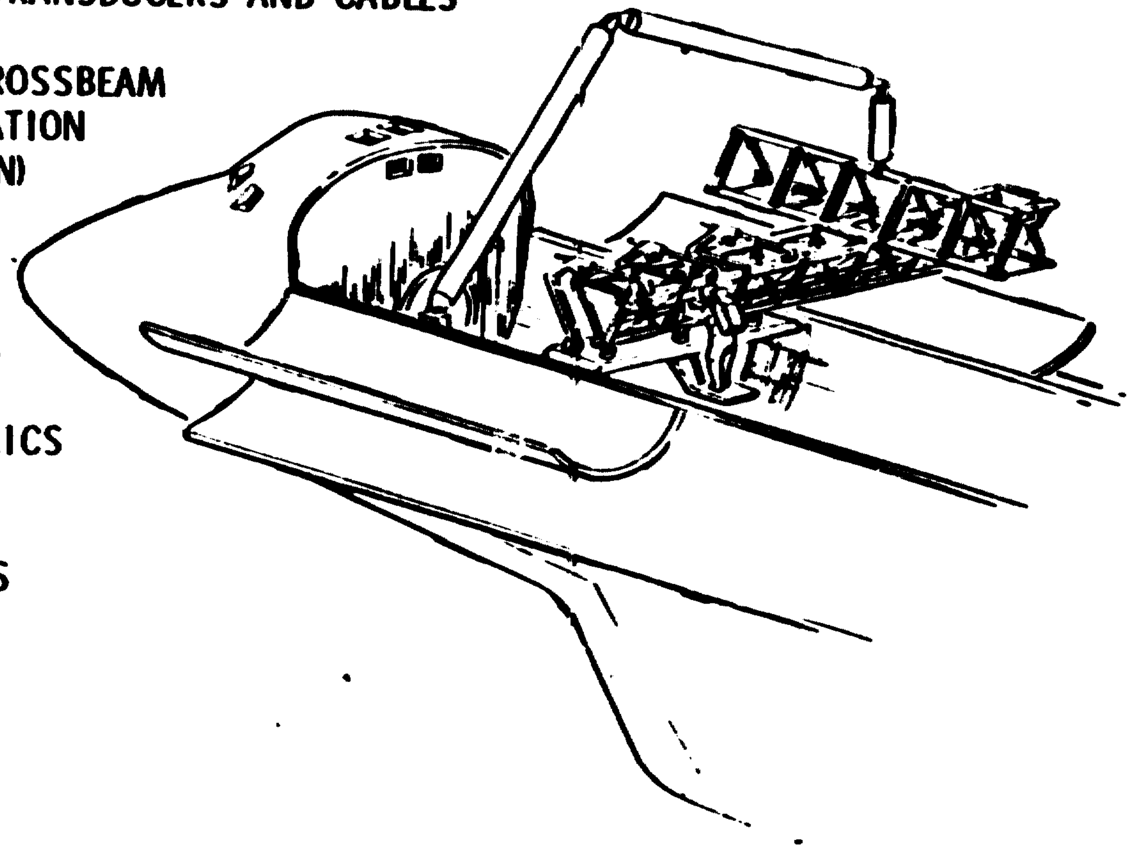


Figure 5-4. Flight Experiment - Group IV

6.0 CONCEPT SELECTION

Section 5.0 described the four experiment concept groups. A further evaluation was made of the four flight experiment groups. Each experiment as described by its objectives was evaluated in accord with its relative development time. Table 6-1 shows the results in a time-phased experiment buildup.

The orbiter services experiment group would take the least amount of development time since the test hardware is relatively simple and is not dependent upon other developments. The deployed/structural dynamics experiment group would take an additional 12 months to develop. The construction equipment effectiveness experiment group would again schedule another possibly 12 months later because of its involvement with the cherry picker and the holding and positioning aid and ground testing and training programs. The Group IV experiments schedule is even later because of the dependence upon the "beam builder" and composite structure design and fabrication.

6.1 EXPERIMENT GROUPS I AND IV

The experiment groups were evaluated again, collectively, relative to their suitability for "early flight" in the orbiter. Experiment Group IV was considered to be outside the realm of "early flight;" therefore, it was recommended that it not be considered further for concept definition in this study. This does not mean that Experiment Group IV is not important; to the contrary, it is an extremely important experiment but is not suitable for early flight as an objective group since it is paced by the availability of the beam builder.

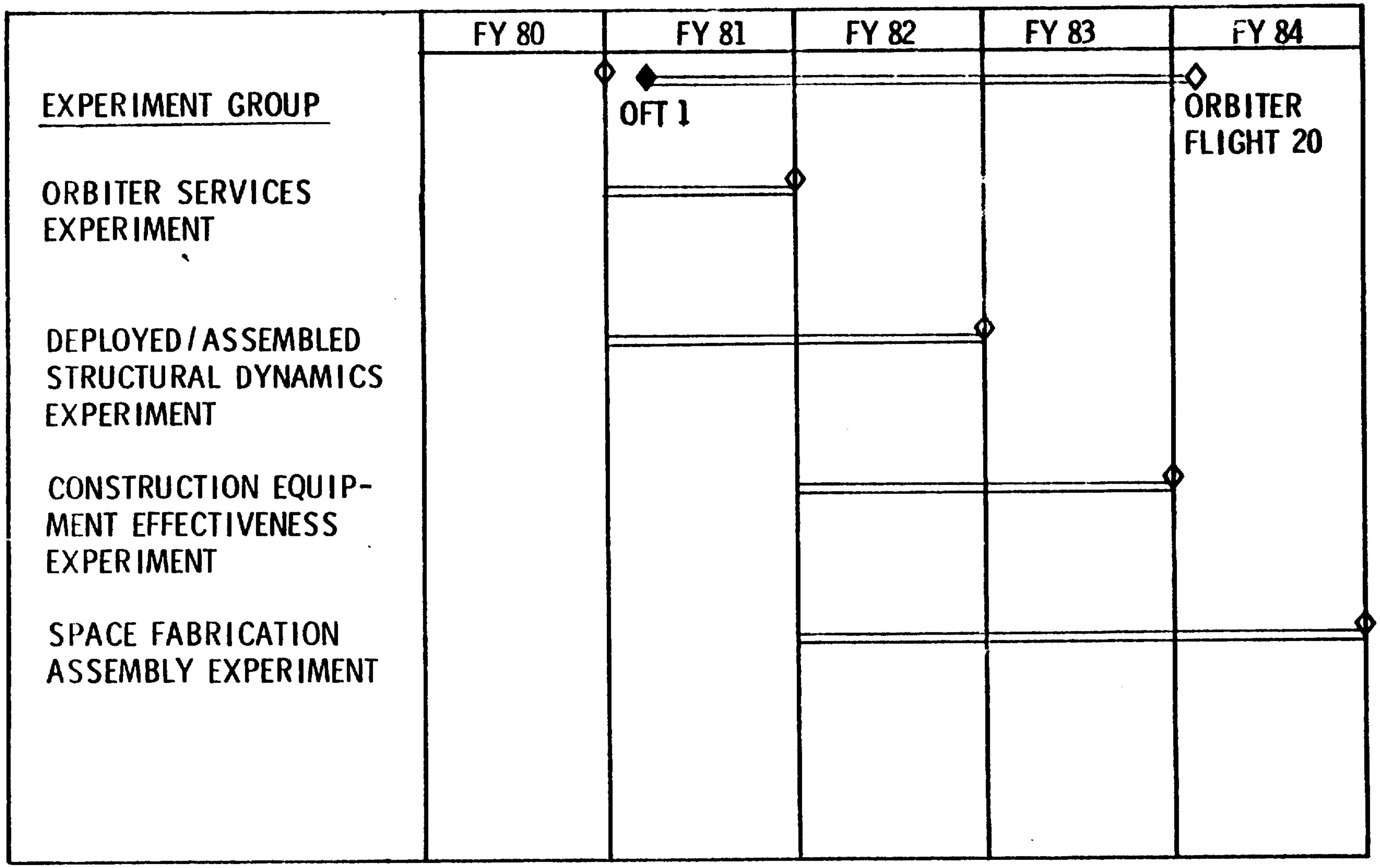
Experiment Group I, Orbiter Services Group, was also examined critically. It was found that all of the information and data that are to be derived as results from the Orbiter Services Experiment will be available on a fragmentary basis from the early orbiter flights. Therefore, it was concluded that Experiment Group I should not proceed into concept definition. This does not mean that the Space Construction program does not require the data. The program requires the data urgently, but it is recognized that it will be available incrementally from early Shuttle flights in time to support the program.

6.2 EXPERIMENT GROUP II

The assembly of large space structures in orbit will require advances in several technology areas. There must be a systematic program of technology development and flight test in large space structures which will lower the technological risk to a point of user acceptance. Experiment Group II (Figure 6-1) will provide the initial cornerstone experiment in the technology development of structures, remotely operated assembly techniques, and structural dynamics.

The objectives of the experiment are multiple. Foremost is to develop an experiment base for dynamic testing and construction operations on orbit. Information to evaluate and develop LSS systems can be obtained such as various sensing

Table 6-1. Time-Phased Experiment Buildup



② DEPLOYED/ASSEMBLED STRUCTURAL DYNAMICS EXPERIMENT

- LOAD DISTRIBUTION STRUCTURE DEPLOYMENT
- ORBITER AND CONSTRUCTION INDUCED DYNAMICS
- STRUCTURAL DYNAMICS

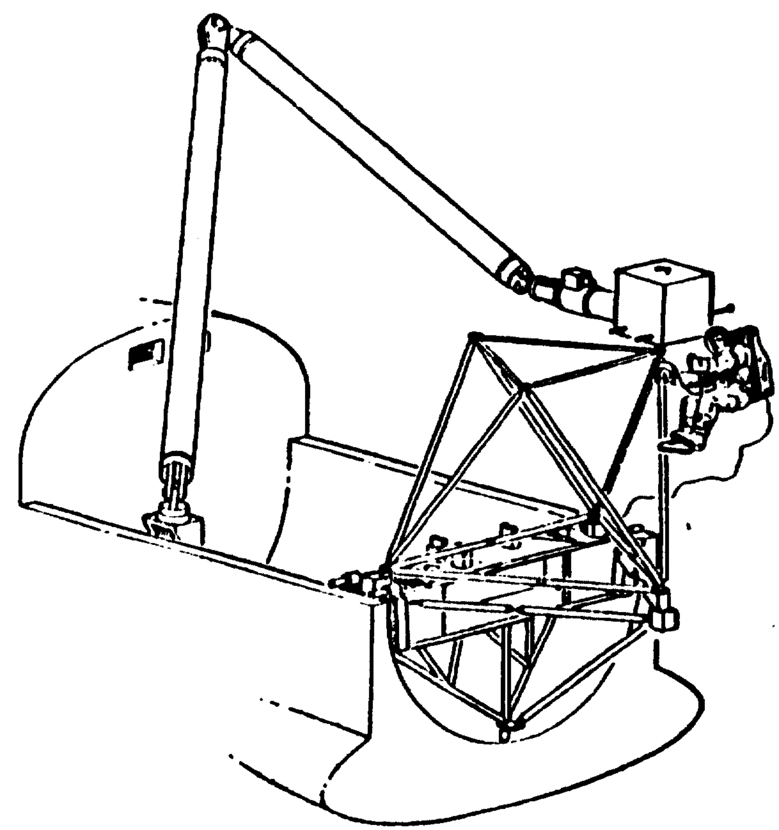


Figure 6-1. Flight Experiment - Group II

methods, influence of zero-g in behavior of the structural system, measured values of damping of the joints in zero-g, and limited characteristics of orbital viscous dynamics.

In the proposed experiment concept, the truss will be single-point excited in a free-free state. Two forms of modal testing will be exercised: sinusoidal-dwell, and single-point random. The opportunity will be available to sense and measure with various instrumentation. Information such as transfer functions of the structure will be obtained. Complex modes which characterize structure, inertia, and damping will also be obtained, as will empirical behavior across joints and various local aspects of the structure in-orbit environment. These tests will provide the basic types of information required for the design of an attitude/velocity control system; e.g., performance requirements, the disturbing torque environments, and the plant dynamics as shown in Figure 6-2. With this information, the control laws can be formulated for the overall system.

A necessary input to the mechanization of any control system - conventional, adaptive, or optimal - is a knowledge of the plant dynamics. The plant dynamics has to start from acknowledge of the discrete elements (trusses, joints), and pyramid the knowledge to predict and verify the behavior of basic structural modules. This knowledge may be completely defined, to some accuracy, prior to mechanization of the system, or refined in use for adaptive or optimal designs. The critical parameters of an elastic structure are the modal frequencies, modal gains or inertias, and modal damping. The first few modal frequencies and gains can be estimated reasonably well for conventional structures, but the modal damping cannot be estimated well for any mode. Controllers using mode control required accurate representation of the damping mechanism for the uncontrolled mode domain. The degree of stability depends on the form for damping. Adaptive controllers circumvent the need for such a high level of prior knowledge of a system, but have attending requirements.

The bottom line of Figure 6-2 shows the test objectives accomplished by Experiment Group II and how they form the building blocks for a better understanding of the plant dynamics. The ability to perform the vibration tests in space and the data measurements is an important facet of the test objectives. Due to the test environment and low frequencies, the type of measurement sensor is important. The structural response measurement is needed to evaluate the response characteristic of the test module. Methods employed could have a bearing on the procedures to be used for an operational LSS wherein there is an adaptive control system.

In addition to dynamic tests, other test objectives associated with construction and on-orbit assembly will be achieved. Multi-point attachment of one structural module to another structural module would be demonstrated by the three-point mating of Experiment Group II. It is recognized that any structural module would have a certain degree of dimensional uncertainty due to thermal, manufacturing, deployment, and on-orbit assembly. Therefore, trying to mate with three hard parts could be difficult unless the design has adequate dimensional uncertainty allowances built into the attachment fitting.

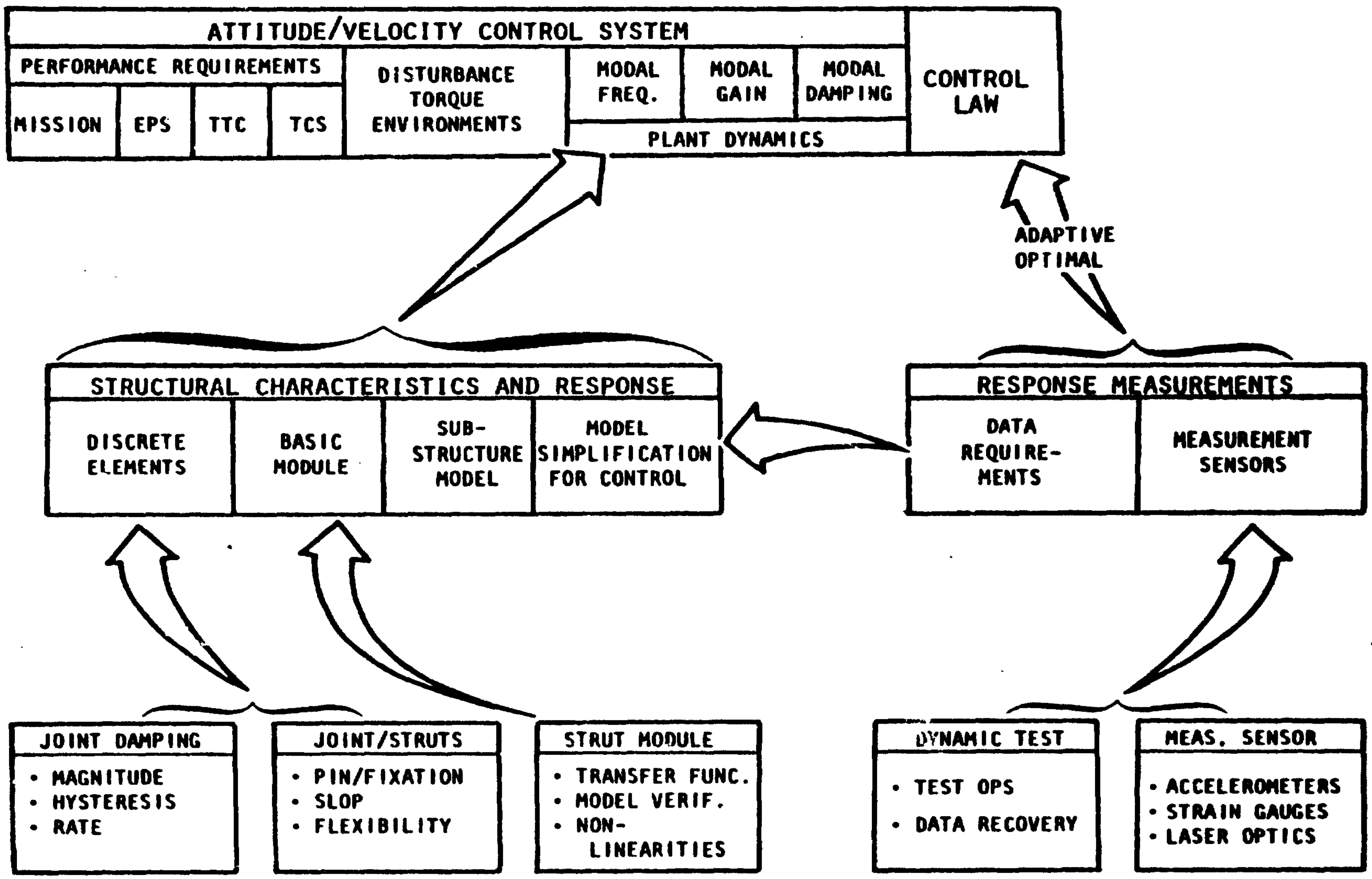


Figure 6-2. Flight Experiment - Group II

Experiment Group II, as proposed, has various operational procedures and durations that will fully exercise the RMS and its operator. This would provide a meaningful measure of the utility and extended work performance under space operations.

6.3 EXPERIMENT GROUP III

Experiment Group III, Figure 6-3, exercises many of the critical operations technology modes of an LSS. Operations technique verification, timelines, construction equipment interfaces, man machine relationship, and EVA performance in construction tasks have become very important to the operations analysis and mission planning functions. For example, the total assembly and operations startup of the Engineering and Technology Verification Platform is estimated to take three Shuttle flights. If these estimates are optimistic and some tasks take significantly longer then the whole planning base is invalid. This backs up into equipment design, cargo manifesting, mission planning, Shuttle planning and total program funding.

Experiment Group III provides a controlled test bed to evaluate the "cherry picker" concept related to its performance with the RMS and to the performance of specific construction tasks. Specific construction tasks will be performed with the RMS, cherry picker and EVA such as the deployment and installation of an attach port, the installation and removal of a module, and the attachment of lines with EVA and RMS cooperation. The test will also provide a means for evaluating the holding and positioning aid device. This Experiment Group III baselines the construction operations, equipment, and man-machine data that are required very early in the large space platform construction program. The importance of this experiment group to the mission planning functions cannot be over-emphasized.

6.4 SELECTED CONCEPTS

Experiment Groups II and III are recommended for further definitions as depicted in Figure 6-4.

Since the experiment groups can be scaled down by not being quite so ambitious or reducing the complexity of the test article or test approaches, it is also recommended that four experiments be selected for concept definition as shown in Figure 6-5: Experiments 2 and 2 Prime, and Experiments 3 and 3 Prime. These concepts are carried into the concept definition phase.

These recommendations were presented to NASA/JSC study management in November, 1979. JSC study management directed Rockwell to proceed into concept definitions.

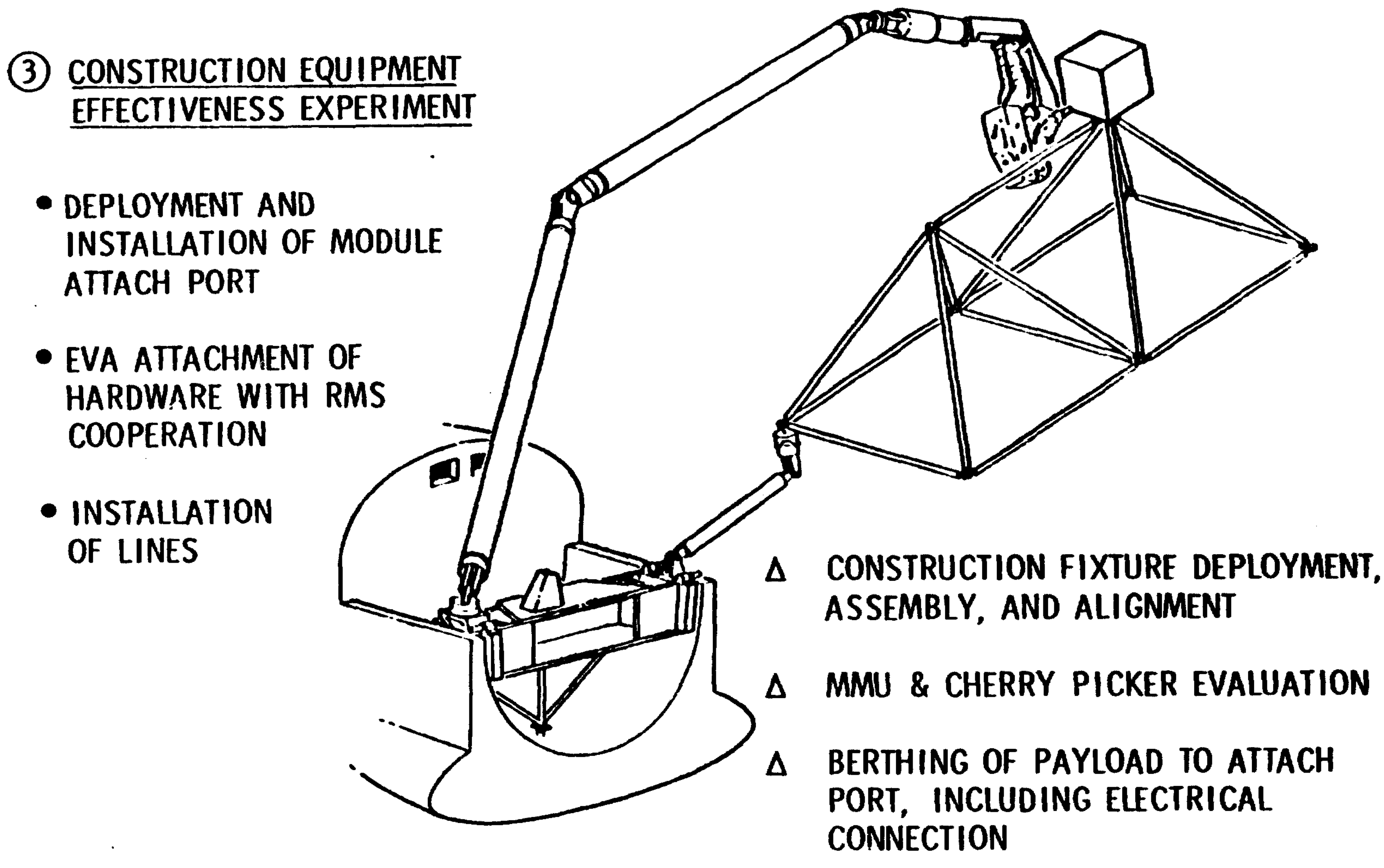


Figure 6-3. Flight Experiment - Group III

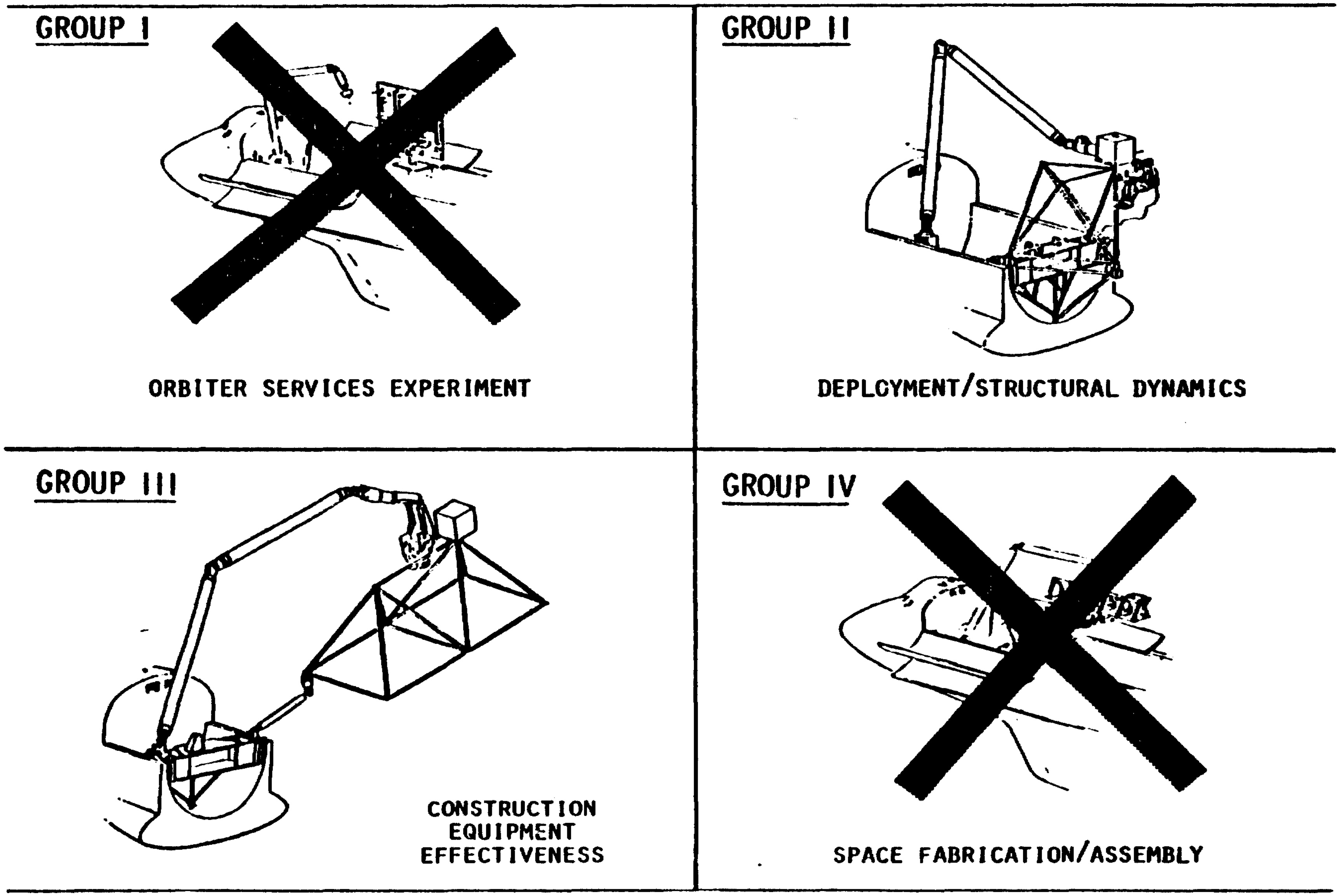


Figure 6-4. Groups II and III Selected for Further Definition

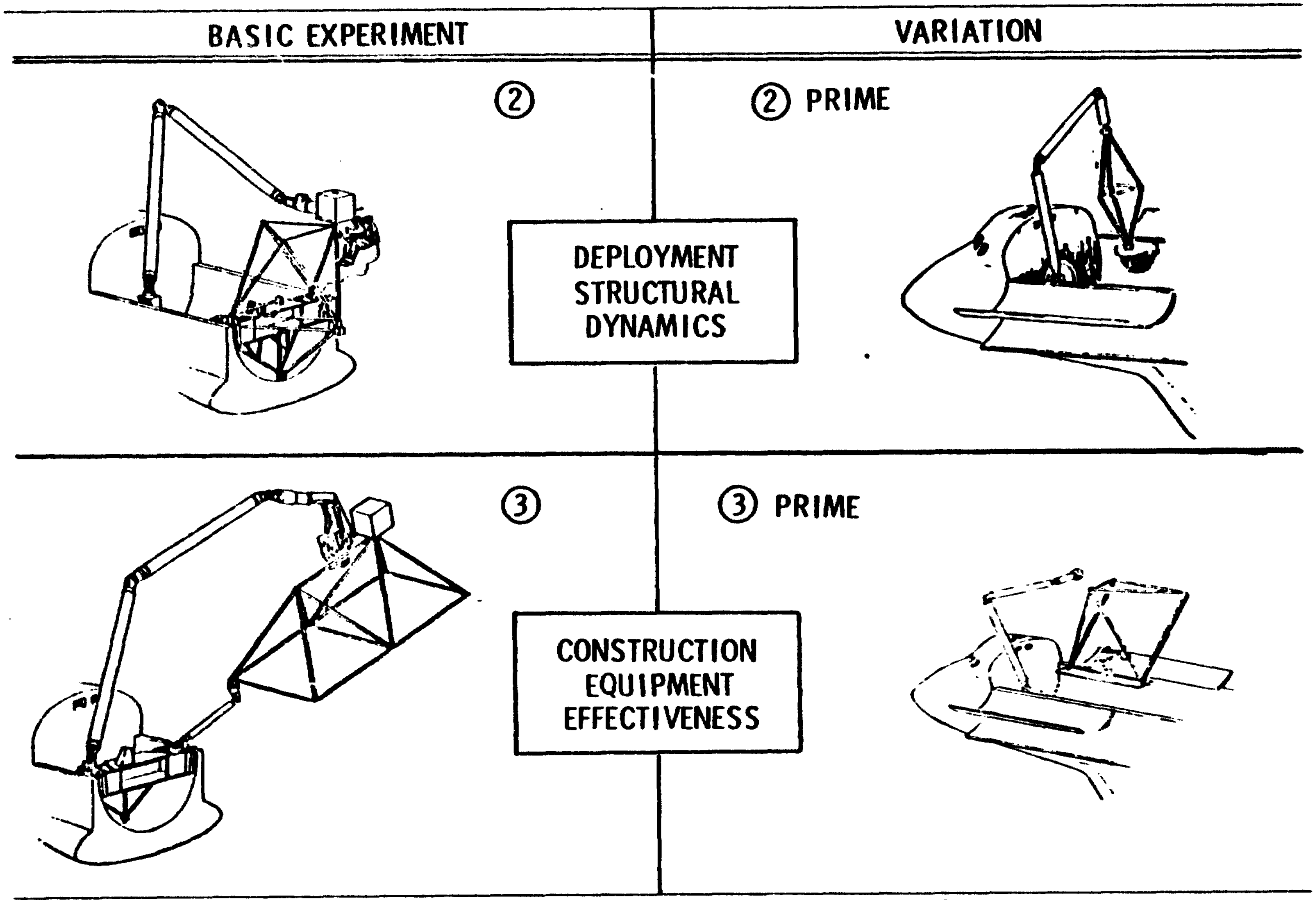


Figure 6-5. Two Basic Experiments With Two Variations Selected for Definition Phase

7.0 SELECTED EXPERIMENT CONCEPTS DEFINITION

The two basic experiments and their two variations, selected in Section 6.0, are described in detail in this section. These four experiments were investigated in sufficient detail to identify the required types of structural elements, flight support equipment, and the operational procedures to accomplish the required test objectives. Each test structure and construction equipment was designed to be representative of useful projected concepts associated with the class of large space structures and their on-orbit construction.

All of the design hardware for each experiment is discussed in this section, and potential design concept details are suggested. There are many other varying concepts that would fulfill the basic test objectives. For the designs conceived, a typical mission scenario has been constructed and a mission timeline composed based on best estimates of data relating to planned space construction operations.

Determining the feasibility of orbiter based large space systems (LSS) construction is the general purpose of the several early flight experiments being discussed in the current study. It is therefore important that the preliminary experiment analyses examine the important experiment interfaces with the orbiter. The experiment/orbiter interface section provide summary experiment/orbiter interfaces for the four LSS experiment alternatives being described in detail in the study.

Table 7-1 provides a generic listing of major experiment components and support equipment required for each of the four experiments being analyzed. A listing of selected orbiter systems and subsystems considered for the interface analyses is shown in Table 7-2. More detailed discussion of these specific orbiter/experiment interfaces will be given in the individual experiment description sections.

Several other areas of experiment/orbiter interfaces must be formalized during a follow-on detail design study of the experiments. These include preparation of statements that will provide accurate weight estimates of all the flight components of the experiment. In conjunction with the weight statement will be the determination of the center of gravity of the experiment assembly for both the boost configuration and also for the deorbit configuration if this should be different. Only preliminary weight estimates are provided for this study.

An additional area requiring analysis of the proposed experiments is the preparation of a power profile and a total power consumption estimate for the experiment operations. These also are a major input to the overall mission planner. Average estimated power levels and durations are useful for preliminary planning but peak power levels and durations also must be identified. These power utilization plans may require revisions for compatibility with the total mission. Other requirements for consumables (e.g., MMU replenishment) must be estimated.

Table 7-1. Experiment and Support Equipment Matrix

COMPONENTS AND SUPPORT EQUIPMENT	EXPERIMENT 2	EXPERIMENT 2 PRIME	EXPERIMENT 3	EXPERIMENT 3 PRIME
1. DEPLOYABLE STRUCTURE MODULE	X	X	X	X
2. EXPERIMENT CONTAINER	X	X	X	X
3. CONTAINER SUPPORT	X	X	X	X
4. SHAKER MODULE	X	X	X	X
5. UMBILICALS, WIRE HARNESS, ETC.	X		X	
6. HANDLING AND POSITIONING AID (HAPA)			X	X
7. RMS	X	X	X	X
8. SPECIAL END EFFECTOR (SEE)	X			
9. MANNED MANEUVERING UNIT (MMU)			X	X
10. CHERRY PICKER			X	

Table 7-2. Orbiter and STS Systems and Subsystems for Experiment/Orbiter Interface Analyses

1. ORBITER PAYLOAD (P/L) BAY STRUCTURE
2. P/L BAY PALLET OR EQUIVALENT EXPERIMENT EQUIPMENT SUPPORT STRUCTURE
3. ORBITER RMS
4. AVIONICS SUBSYSTEMS:
   - COMMUNICATIONS AND TRACKING
   - DISPLAYS AND CONTROLS
   - CAUTION AND WARNING
   - DATA PROCESSING AND SOFTWARE
   - ELECTRICAL POWER DISTRIBUTION AND CONTROL
5. ELECTRICAL POWER SYSTEM
6. P/L BAY LIGHTING
7. CLOSED CIRCUIT TELEVISION (CCTV)
8. AFT FLIGHT DECK (AFD) CONSOLE
9. AFD CREW (P/L SPECIALIST, MISSION SPECIALIST)
10. EXTRAVEHICULAR (EVA) CREW
11. MANNED MANEUVERING UNIT (MMU)
12. CHERRY PICKER
13. REACTION CONTROL SYSTEM (RCS)
14. P/L GROUND HANDLING SYSTEM

Other mission planning activities which may be required are a data recording profile and the requirements for communication with ground stations during the experiment operations. Crew utilization summaries also must be prepared. This would include identification of skills required for use in pre-flight crew training. Crew scheduling for EVA operations will be an important analysis area because of the additional man-hours expended in pre-EVA and post-EVA conditioning.

Other secondary orbiter interface items which influence experiment operations remain to be analyzed in the future for selected experiment operations analyses. An example of this could be the direct vision available from the AFD console area of the critical experiment activities. The desirability of test operations during daylight or dark portions of the orbit and desired orbiter attitude relative to the sun or the earth would be analyzed. Decisions on items such as these could influence experiment placement in the payload bay and RCS requirements for orbiter.

7.1 EXPERIMENT NO. 2—DEPLOYED/ASSEMBLED STRUCTURAL DYNAMICS EXPERIMENT

This experiment has to be carried on an early Shuttle mission and be relatively low cost. A module representing a secondary attachment structure was selected for this experiment as meeting the study guidelines and was capable of demonstrating and verifying several basic space construction operations and providing limited structural dynamic data.

The structure module consists only of 12 struts and 6 nodes, but important information can be extracted from this module experiment relating to its damping behavior and dynamic characteristics. This information will form an important cornerstone in verifying structural modeling for lightweight multijoint, flexible space structures. With a good understanding of the basic elements, it is possible to predict and develop larger models which are more representative of the overall platform structure.

7.1.1 Configuration Description

The hardware configuration for Experiment Concept No. 2 consists of a structure module, test fixture, subsystem module, flight support equipment, and test measurement sensors.

Essentially, the baseline experimental test structure module is a deployable, berthable, space truss structure that simulates typical flight-weight hardware representative of secondary support structure associated with advanced large space structure configurations.

The Engineering and Technology Verification Platform design (ETVP), Figure 7-1, which has been investigated in detail in the Space Construction Analysis Study was taken as representative of large space structures. The construction analysis has identified several areas of concern in space construction operations. For Experiment No. 2, the structures module (Figure 7-2) represents the secondary attachment structure which supported the ETVP payload and solar arrays to the main structural strongback. The structures module consisting of several struts and nodes is easily identified with other design

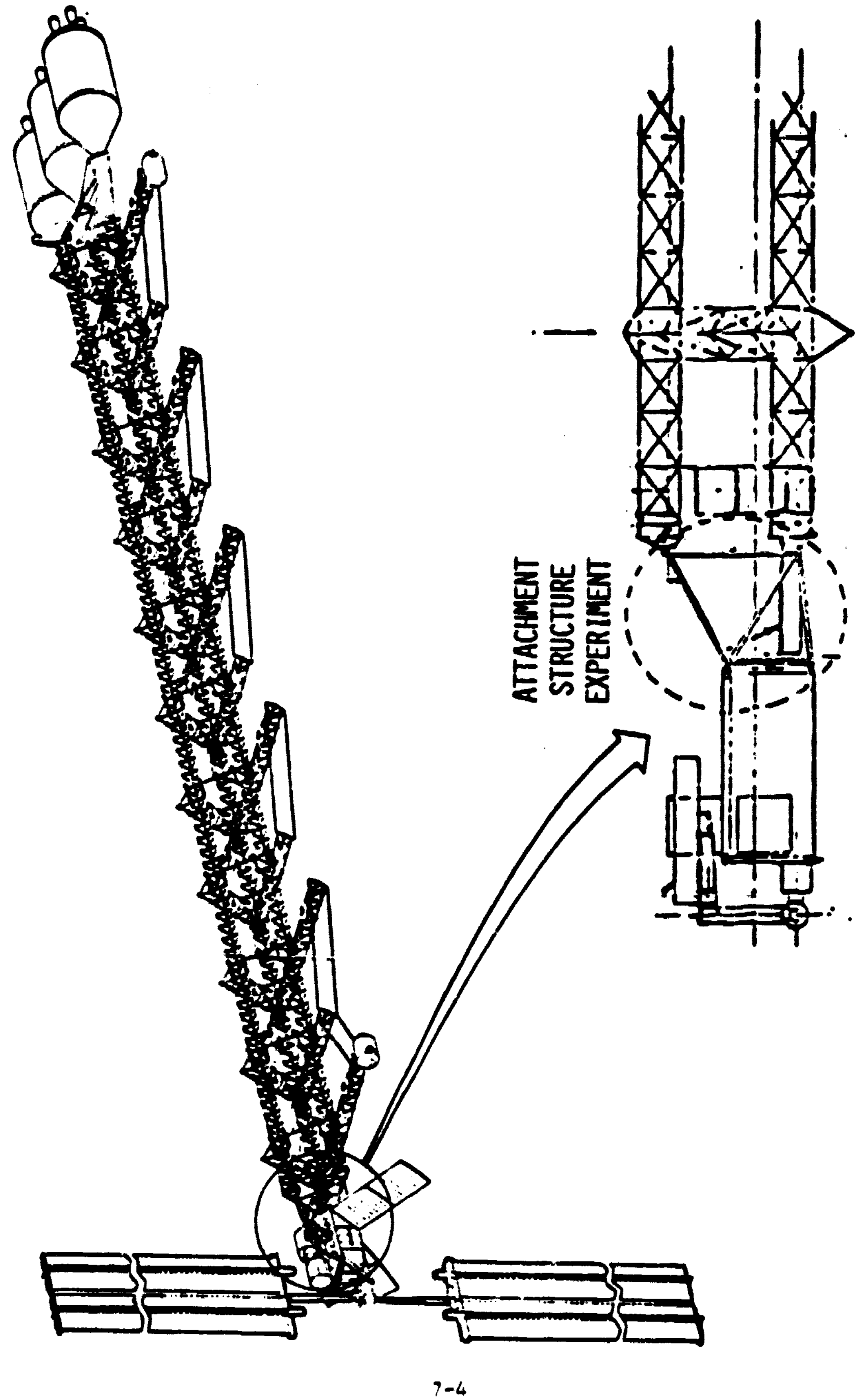


Figure 7-1. Engineering and Technology Verification Platform Design

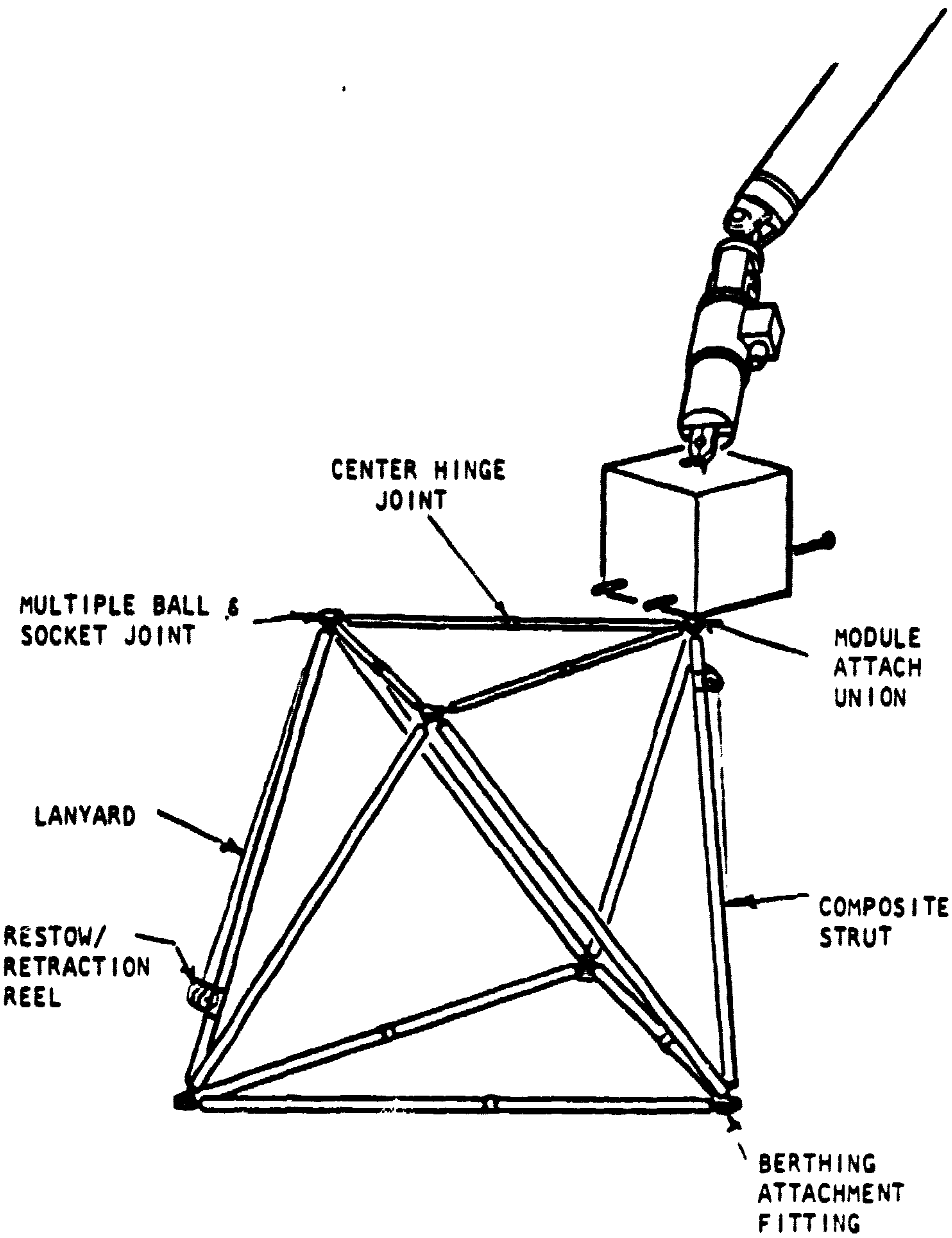


Figure 7-2. Space Construction Strut Module

concepts for scientific and space applications platforms which are deployed, erected, or assembled in space.

The experimental structural module, which is meant to represent a typical flight-weight structure is a tripodal split-leg-truss arrangement consisting of high modulus carbon-fiber/epoxy composite tubular struts joined to multi-point nodal unions, and hinged to provide a compact package when stowed. The overall layout of the experiment within the orbiter's cargo bay is shown in Sheet 1 of Figure 7-3. The folded arrangement and deployment sequence for the structures modules is shown in Sheet 2 of Figure 7-3.

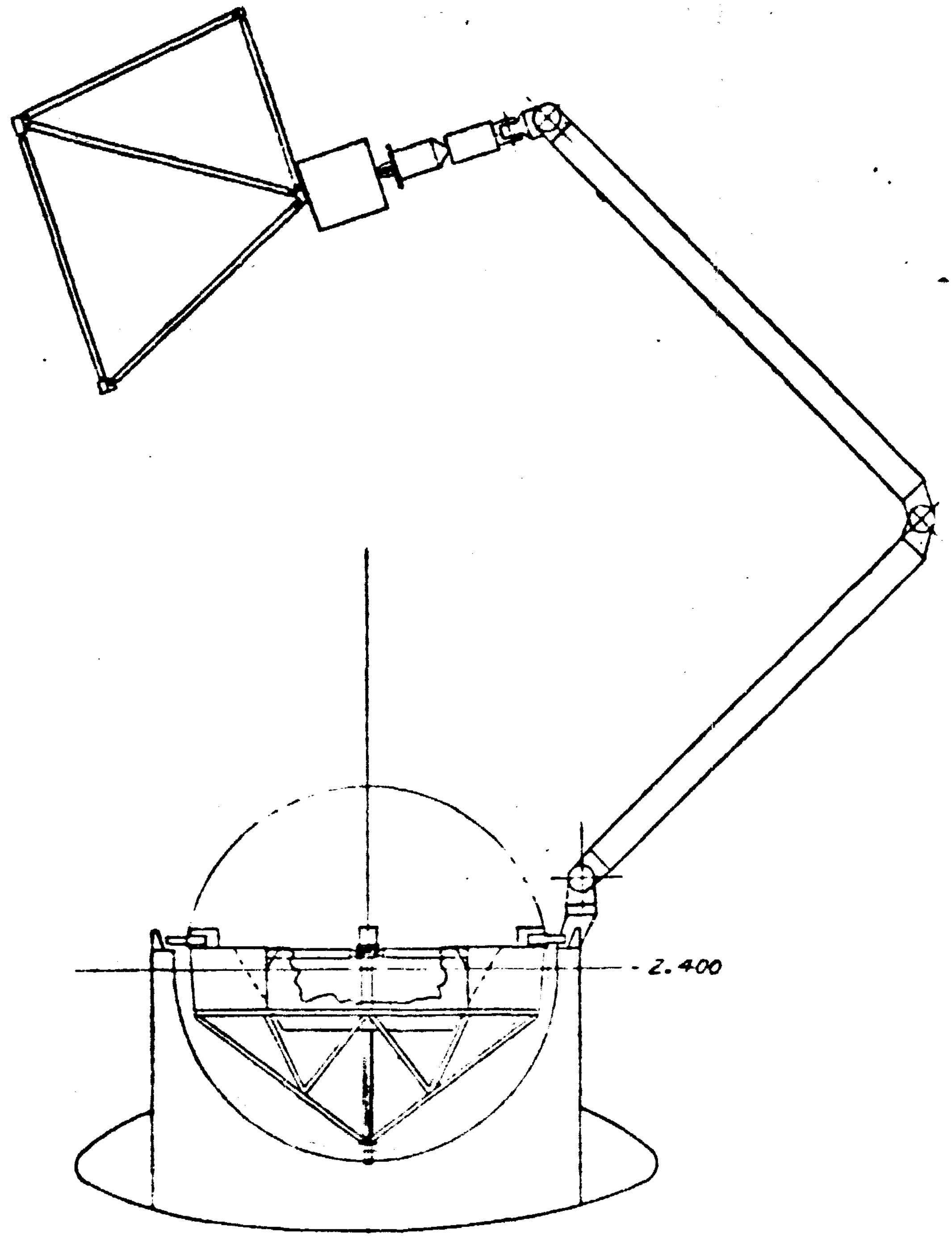
The sizing and arrangement of the struts are a scaled-down version of the structure supporting the forward attachment module. The strut material is graphite/epoxy which has a low thermal expansion coefficient which is considered desirable for the large space structures. The deployment hinges of the structures module and the multi-point attachment fittings can be many different concepts that are applicable to space structures (Figure 7-4).

The efficient joining of structural assemblies in space is a most critical operational requirement that will affect the time and energy needed for assembly and rigidity of the platform structure. In developing a joining concept, it is essential, then, to emphasize operational simplicity coupled with positive engagement and minimum force to effect the joint. In addition, the joint must be capable of being effected without complex tools, and must be forgiving in terms of the angularity of the strut when introduced into the union. The joint could also include length adjustment features to compensate tolerance buildups in the construction. It is also desirable that verification of joint engagement be provided by visual or other positive means.

Joints can fall under one of two classifications—rigid joints and pinned joints. Rigid joints are the type that connect two relatively stationary objects and can be either of the multi-point attachment (e.g., a multi-bolted lap joint) or the single-point attachment (e.g., a bayonet connection). Pinned joints on the other hand, allow relative angular motion between the connected elements. The prime criteria for any joint concept must be the ease of assembly, tolerances to directional and positional misalignment, and the resulting assembly has no noticeable backlash to cause non-linearities (deadbands) in the platform's behavior.

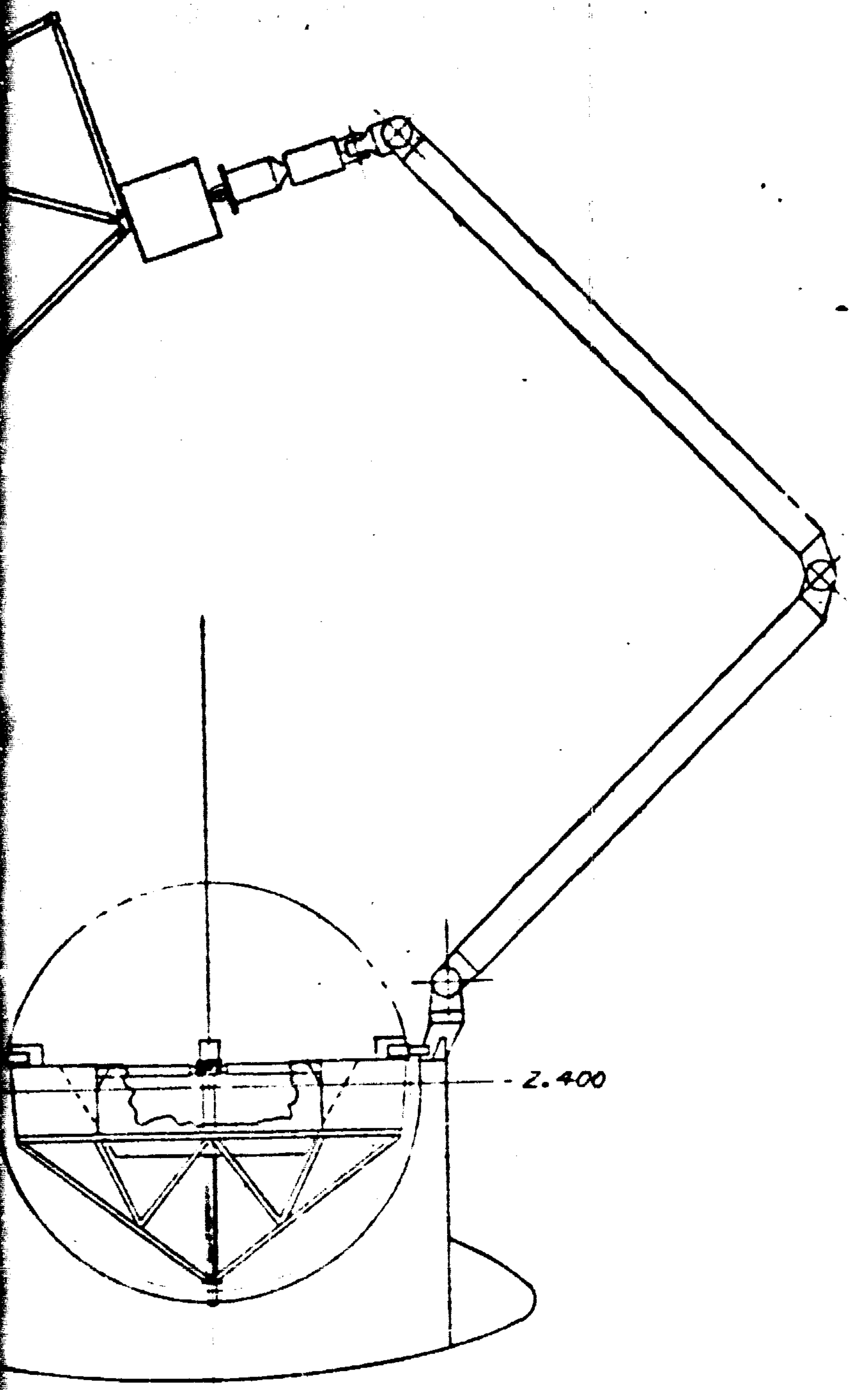
This experiment has the ability to space-test different joints within the one structures module. Different joint deployment behavior and damping characteristics would be measured. The drawings show a particular concept of the ball and socket joint for which test data were available. This is not meant to infer that this concept is the only one recommended for this experiment.

The ball and socket swivel joint originated at Satellite Systems Division, Rockwell International, under NASA-Langley Contract NAS1-14116 (Reference 7.1). The ball end fitting is shown attached to the end of the strut. The union shown is a multi-faceted female fitting for the module construction.



FOLDOUT FRAME

SHOWING RMS ATTACHED FREE STATE MODE



SHOWING RMS ATTACHED FREE STATE MODE

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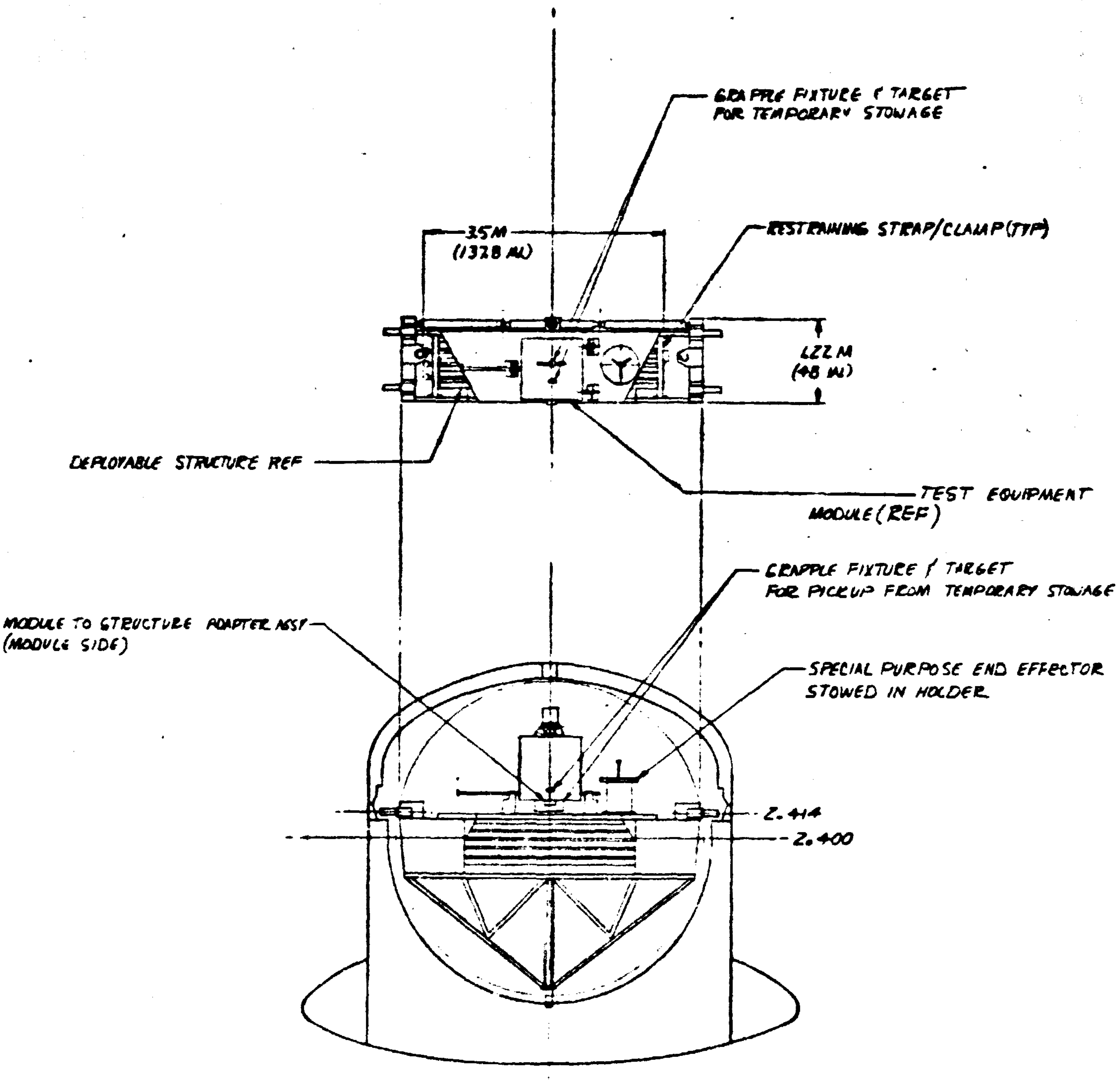

VIEW SHOWING EXPERIMENT STOWED

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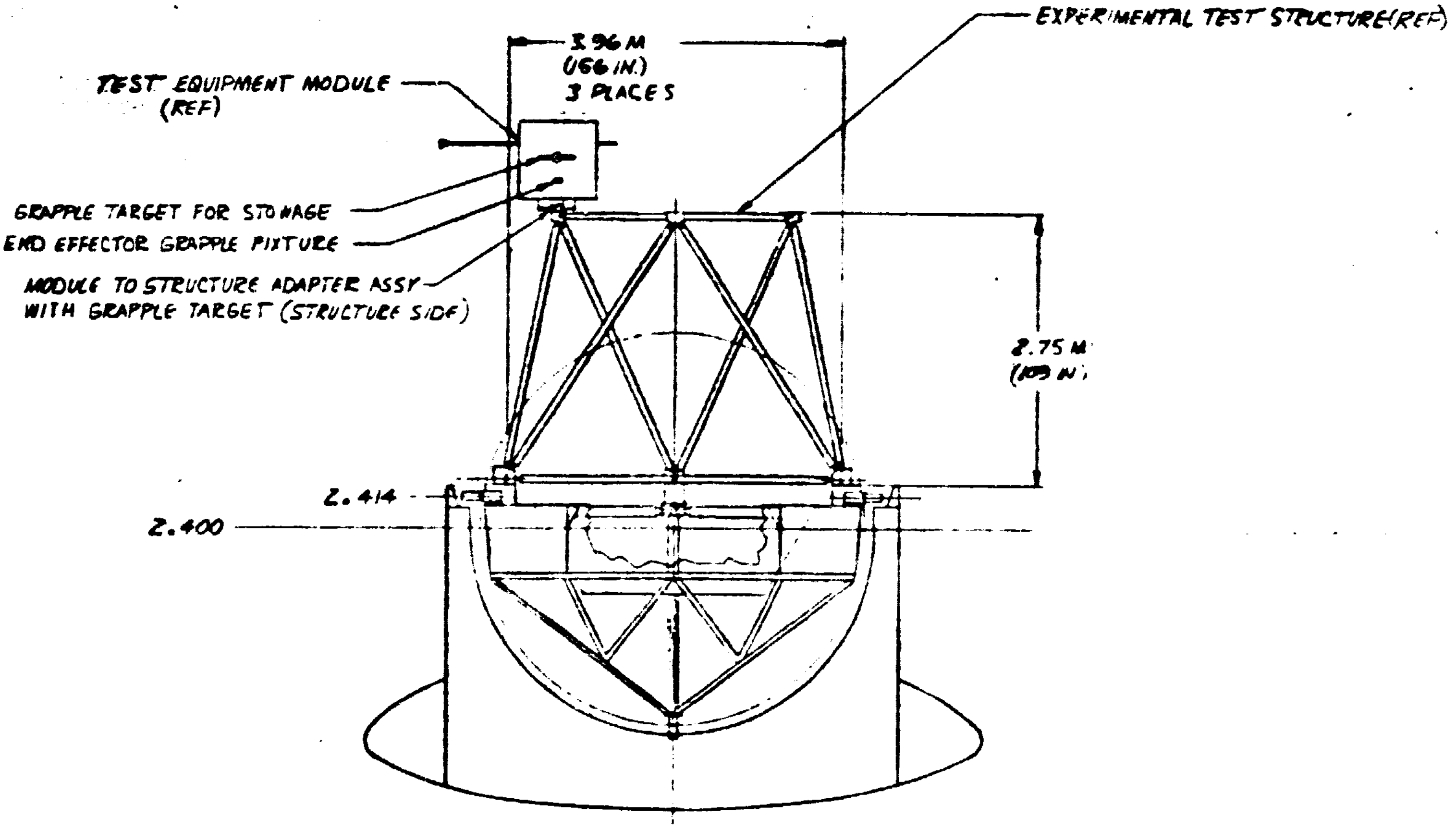

SECTION J-J

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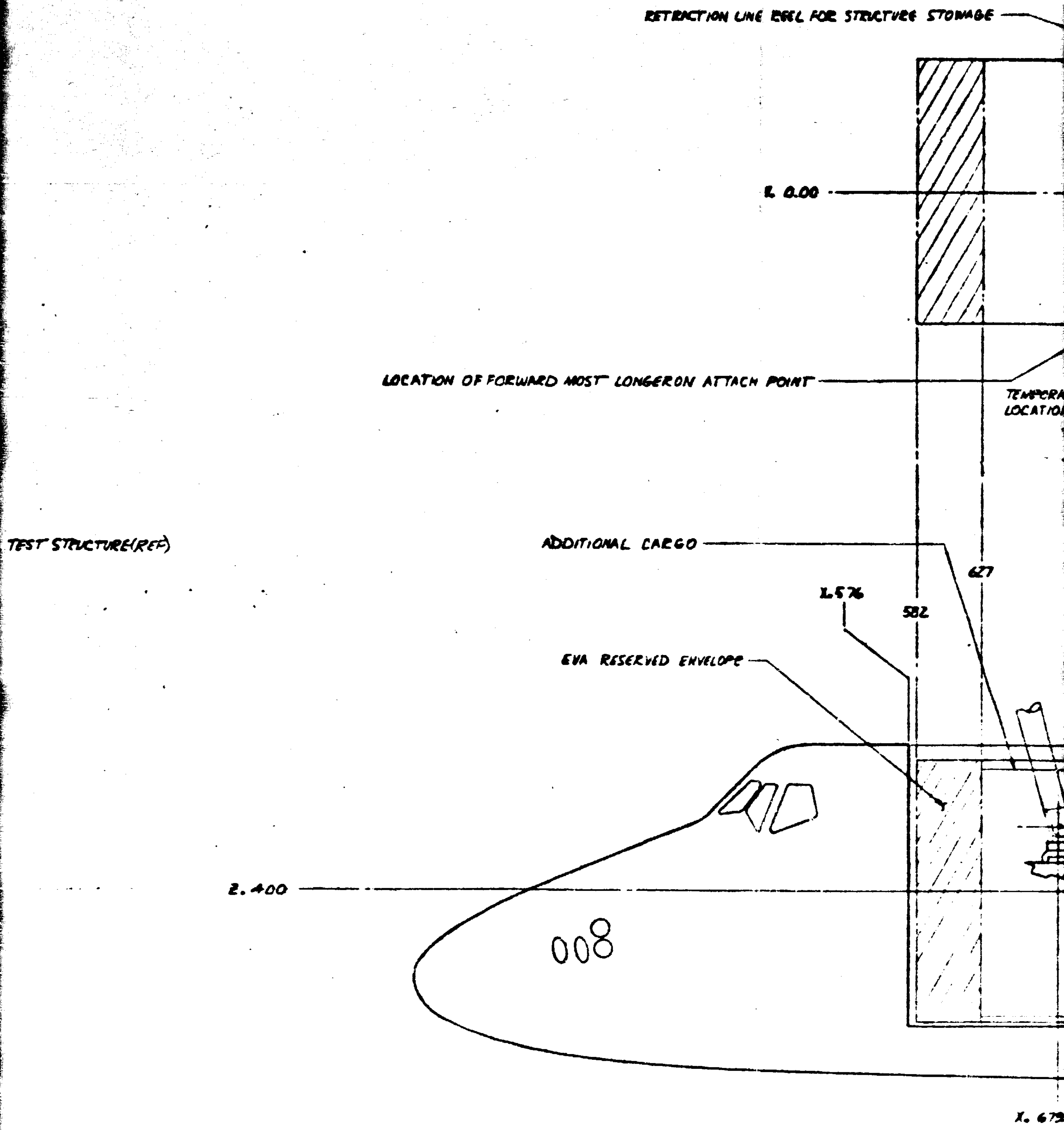

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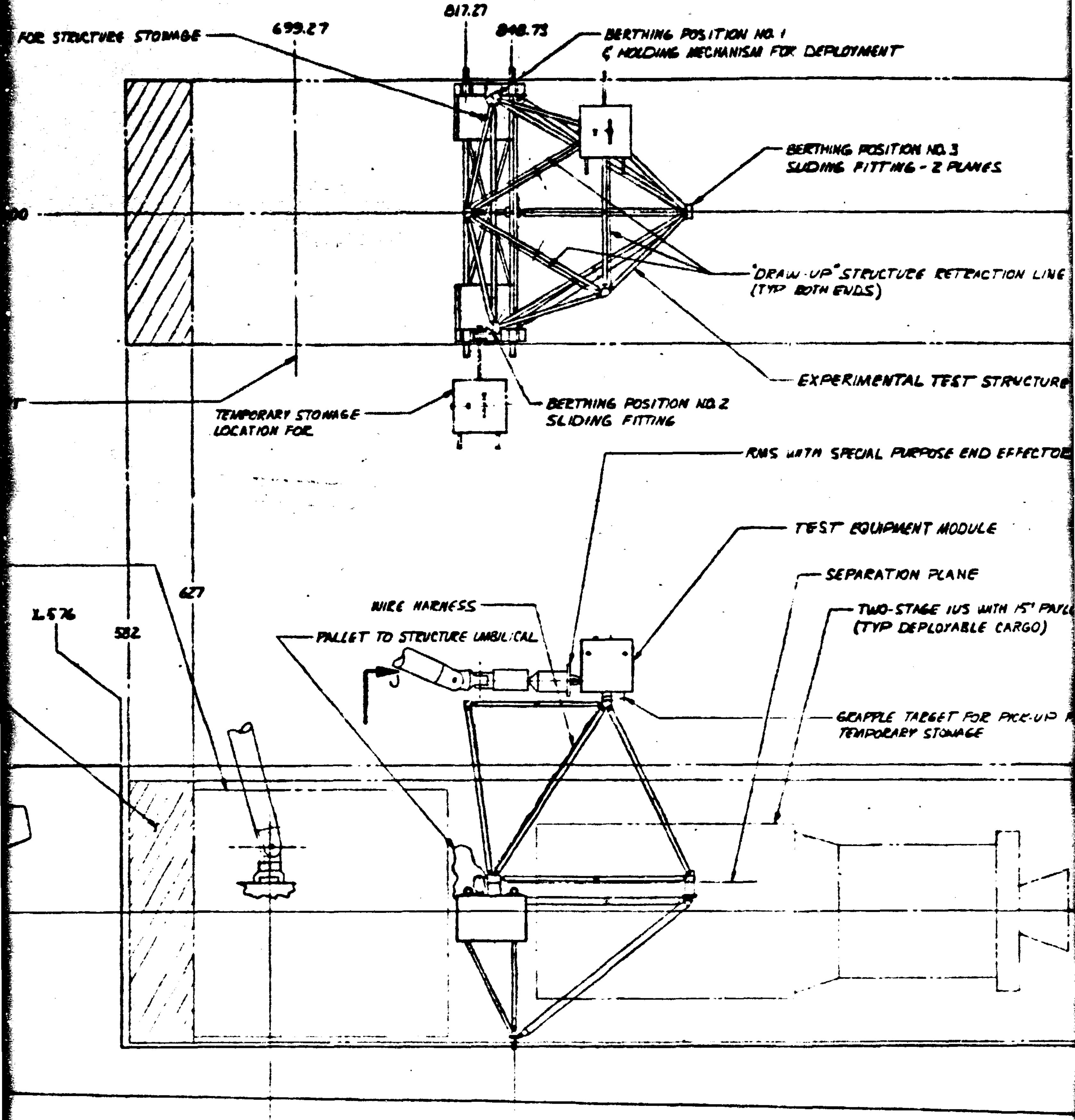

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TION NO. 1
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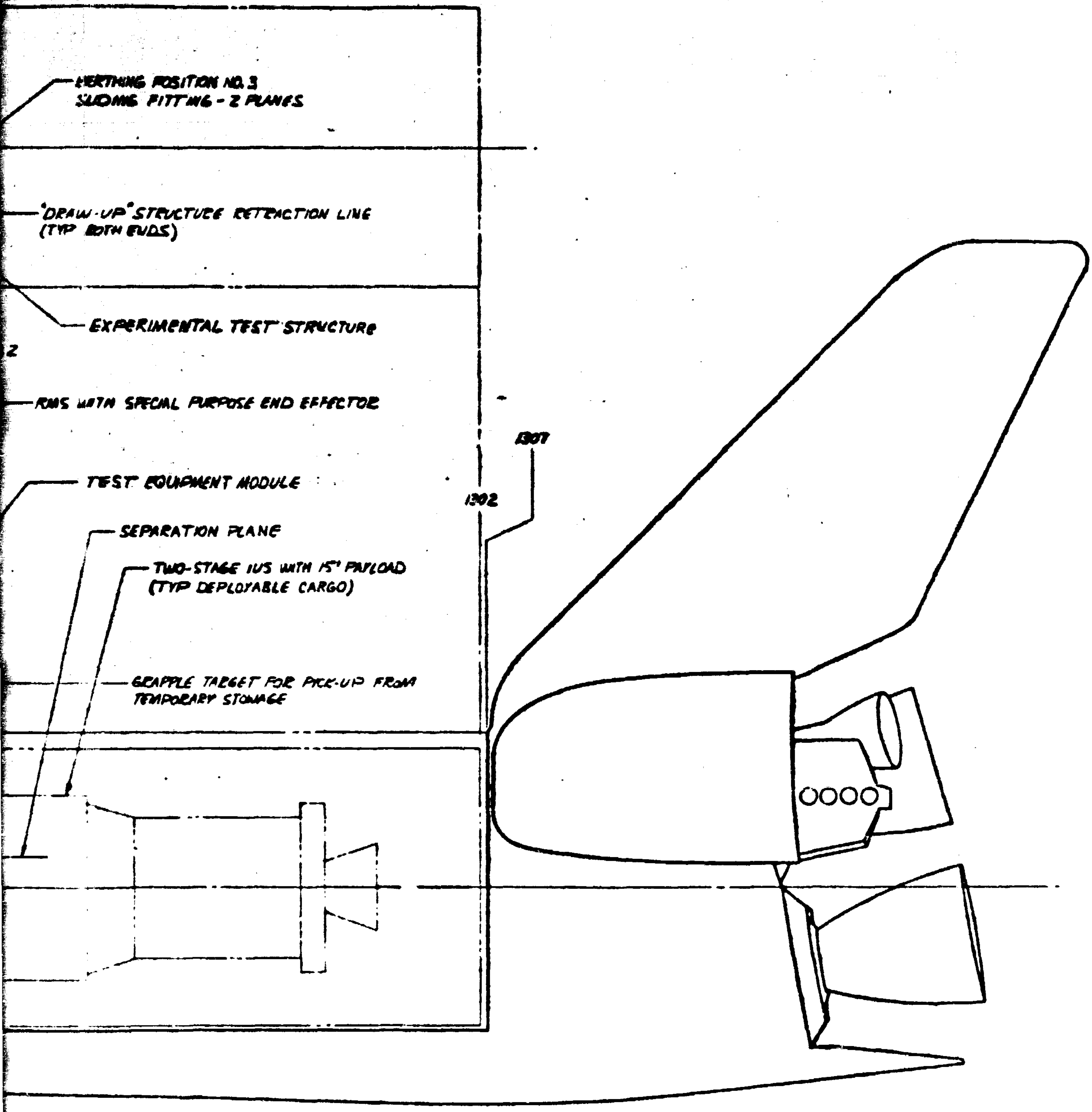

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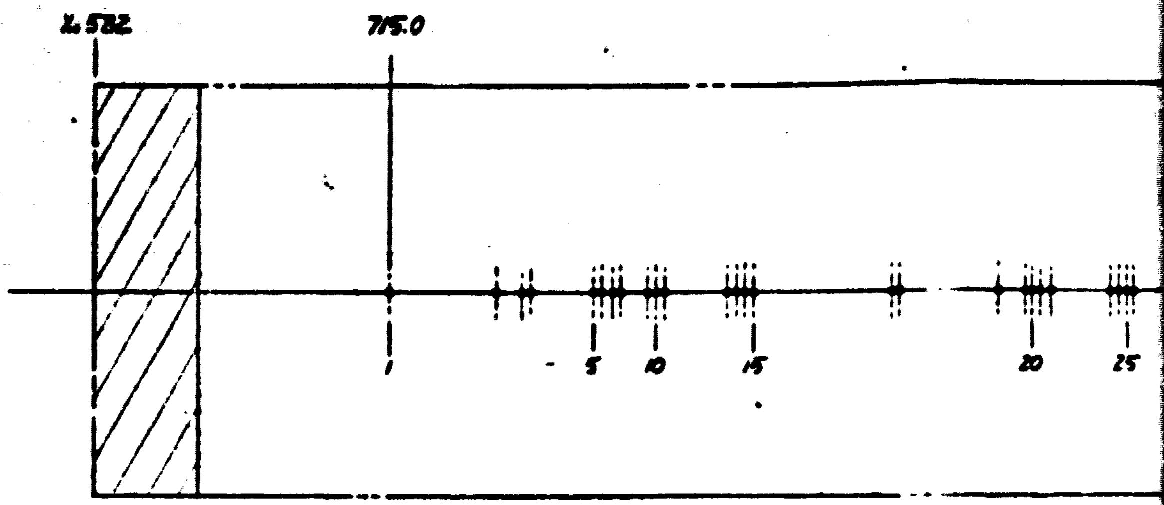

OPTIONAL PAYLOAD BAY LOCATIONS			
NO.	CENTER LOCATION	ATTACH POINTS	
		FORE	AFT
1	715.00	699.27	730.73
2	762.20	746.47 •	777.93
3	774.00	758.27	789.73
4	777.94	762.20	793.67
5	805.47	789.73	821.20
6	809.47	793.67	825.13
7	813.34	797.60	829.07
8	817.27	801.53	833.00
9	829.07	813.33	844.80
10	833.00	817.27	848.73
11	836.94	821.20	852.67
12	864.47	848.73	880.20
13	868.40	852.67	884.13
14	872.34	856.60	888.07
15	876.27	860.53	892.00
16	939.20	923.47	954.93
17	943.14	927.40	958.87
18	990.34	974.60	1006.07
19	1002.14	986.40	1017.87
20	1006.07	990.33	1021.80
21	1010.00	994.27	1025.73
22	1013.94	998.20	1029.67
23	1041.47	1025.73	1057.20
24	1045.40	1029.67	1061.13
25	1049.34	1033.60	1065.07
26	1053.27	1037.53	1069.00
27	1092.60	1076.87	1108.33
28	1096.54	1080.80	1112.27
29	1108.34	1092.60	1124.07
30	1112.27	1096.53	1128.00
31	1139.50	1124.07	1155.53
32	1143.74	1128.00	1159.47
33	1147.67	1131.93	1163.40
34	1151.60	1135.87	1167.33

• AVAILABLE AT PORT SIDE ONLY

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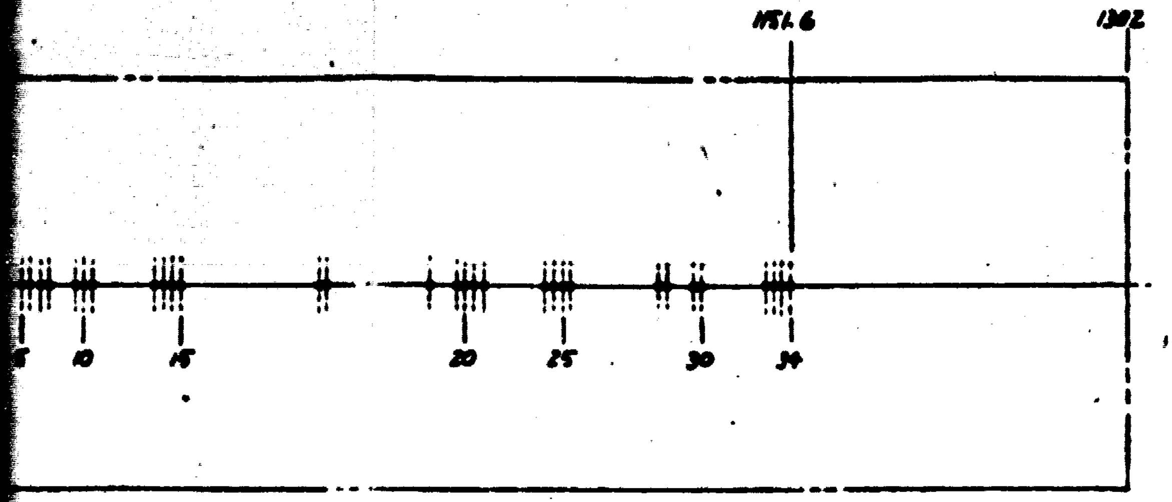

FOLDOUT FRAME

Figure 7-3.

1/40	
FLIGHT EXPERIMENT STRUCTURE-AND SUPPORT HARDWARE	42662-70 SH 1 OF 3

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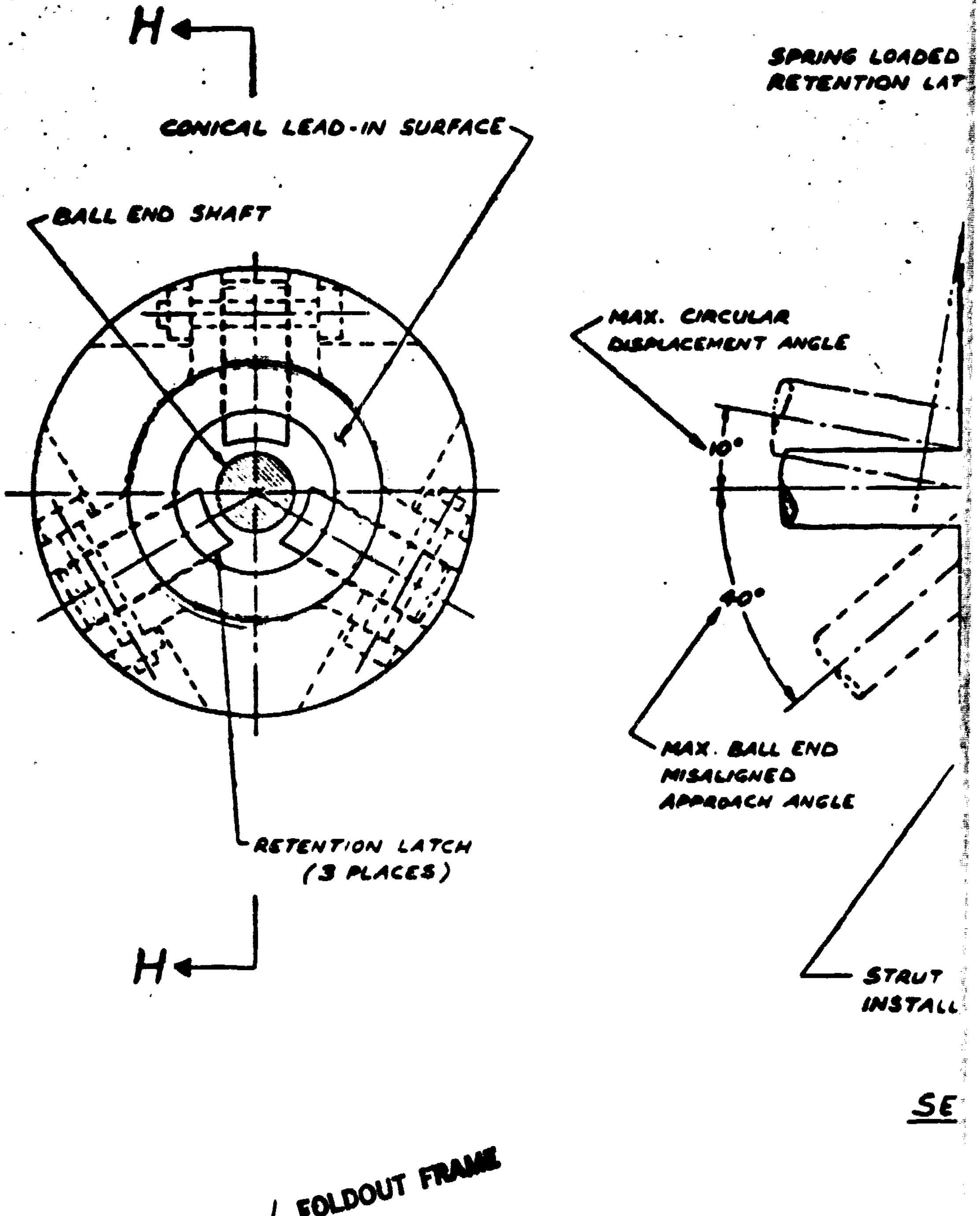

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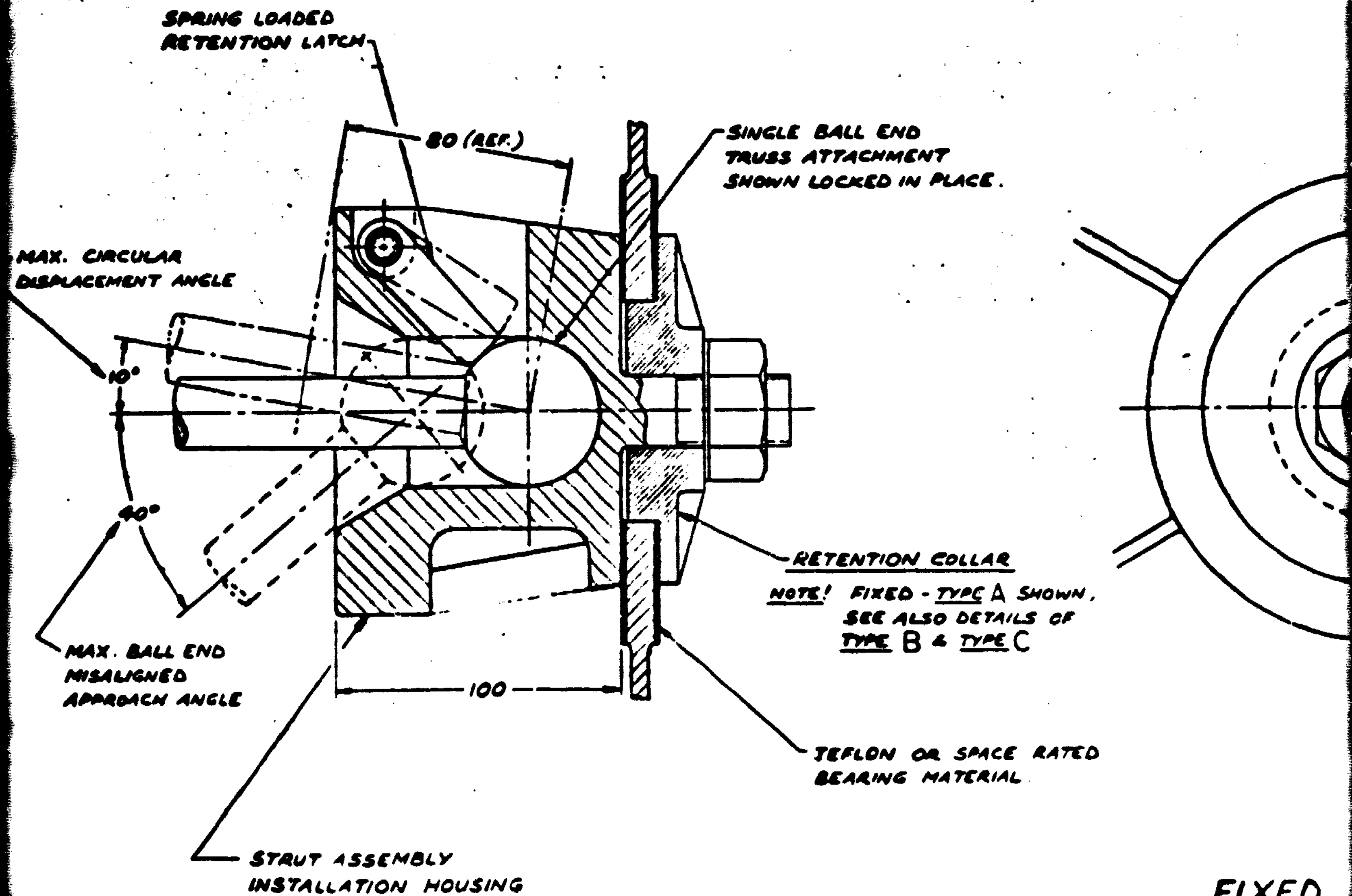

SECTION H - H

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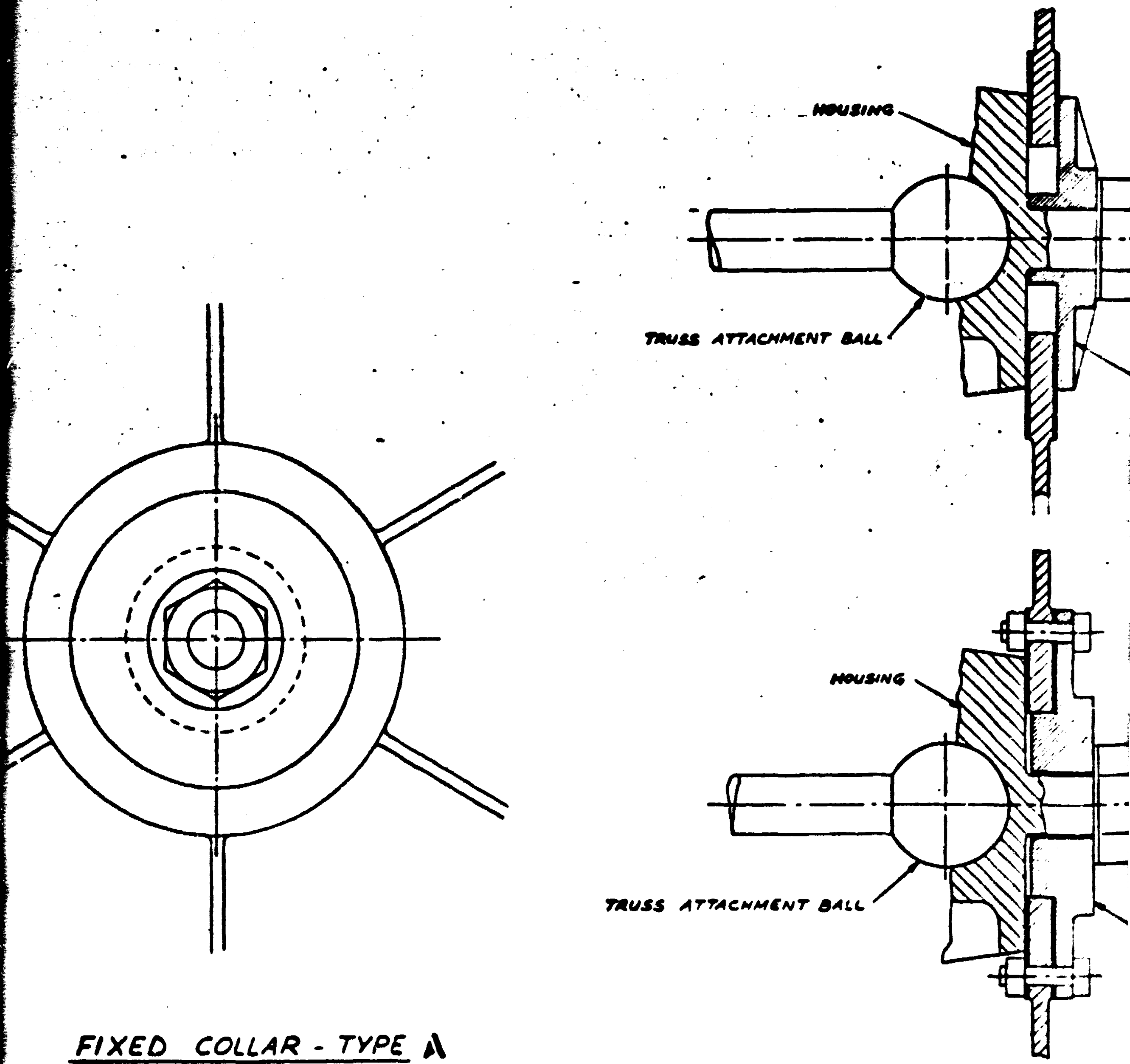
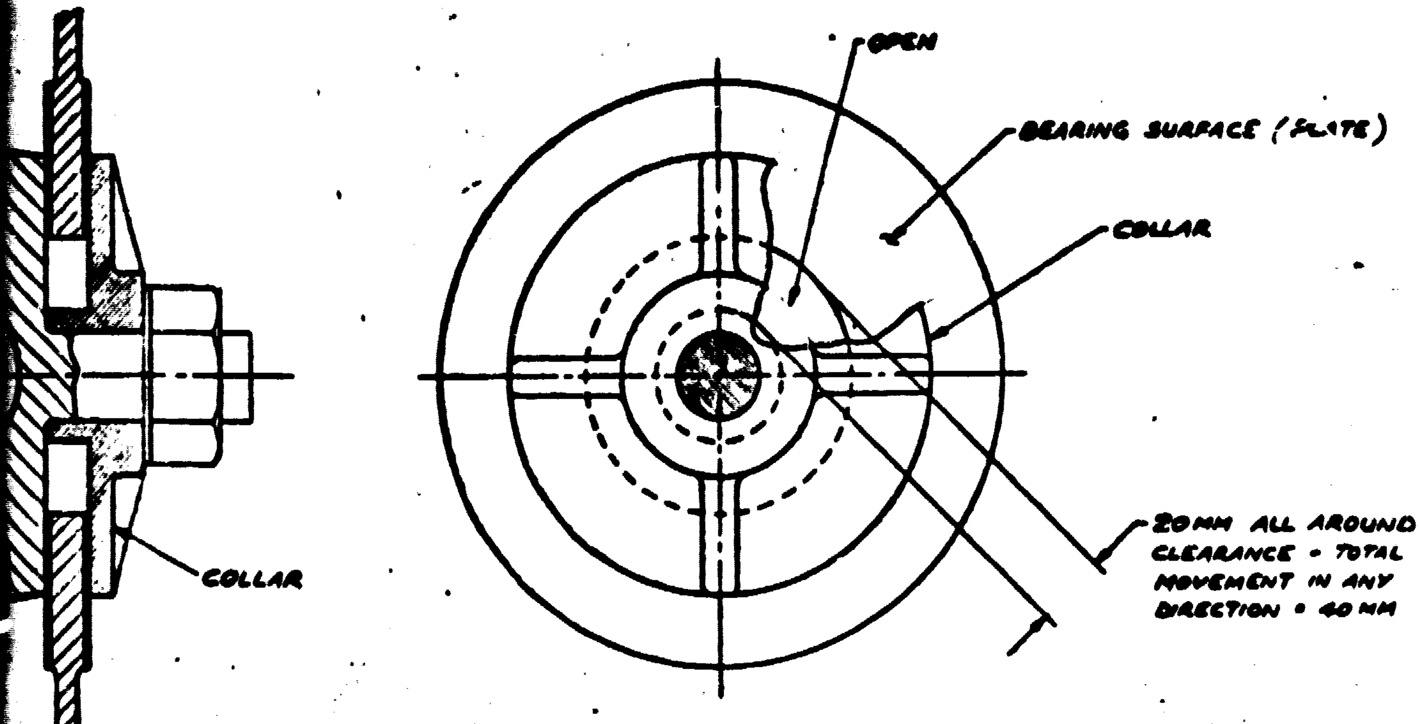


FIXED COLLAR - TYPE A

EXPERIMENT END PORT STRUCTURE ATTACHMENT HOUSING DETAILS

SCALE : FULL

3 FOLDOUT FRAME



FLOATING COLLAR - TYPE C

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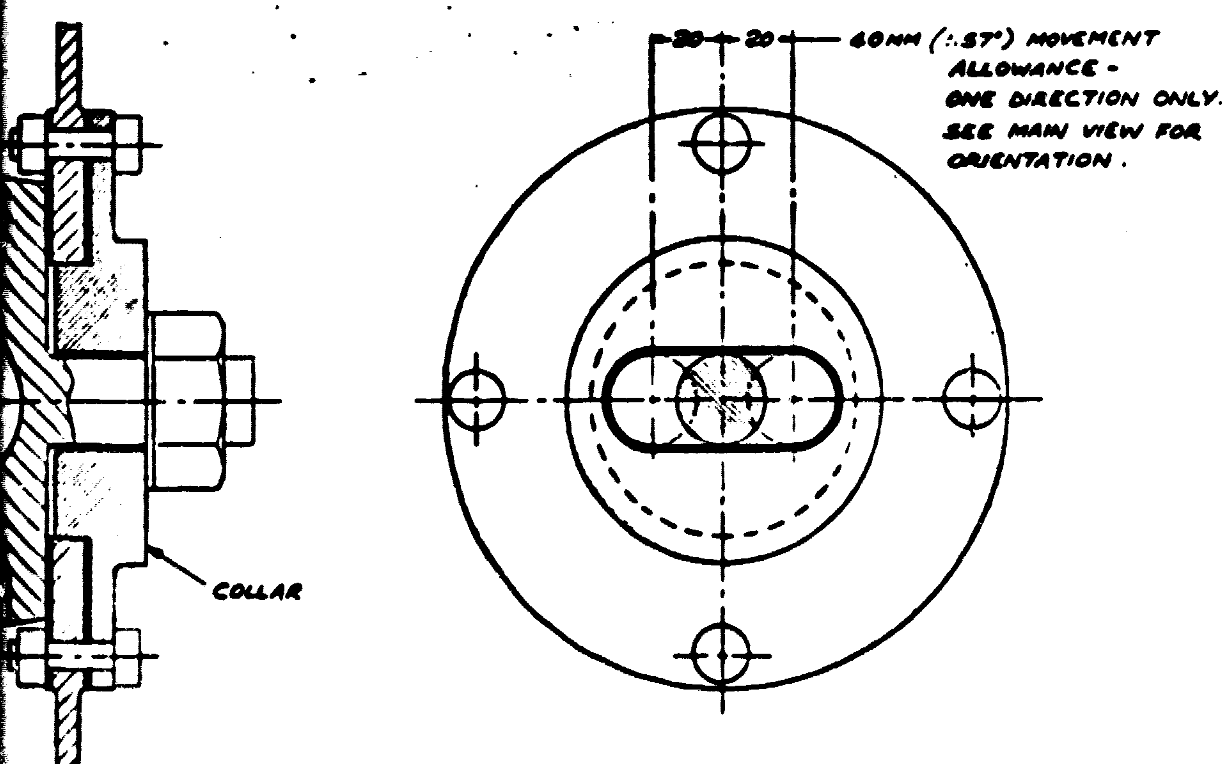

LINEAR ALLOWANCE COLLAR - TYPE B

ETAILS

4

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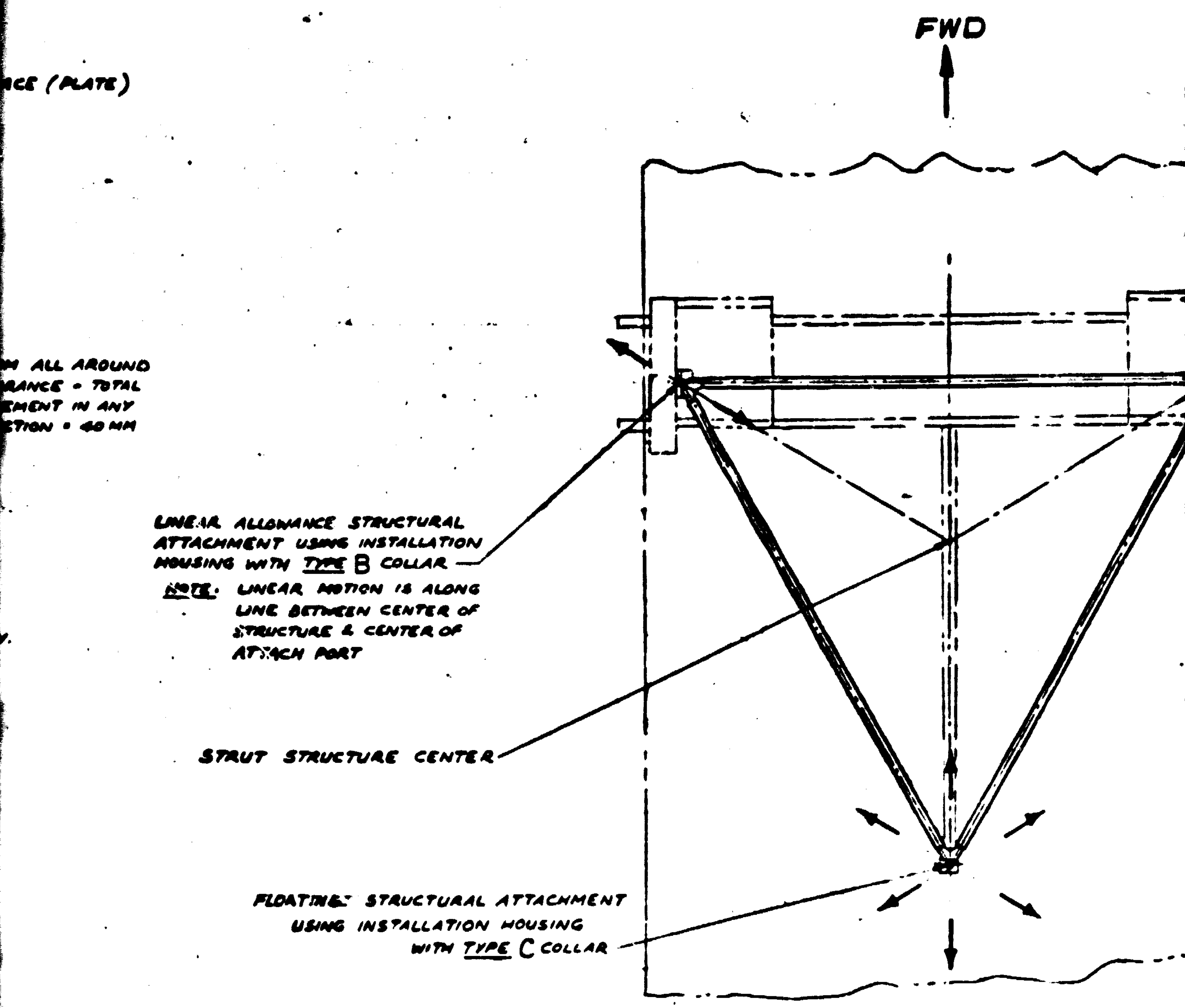
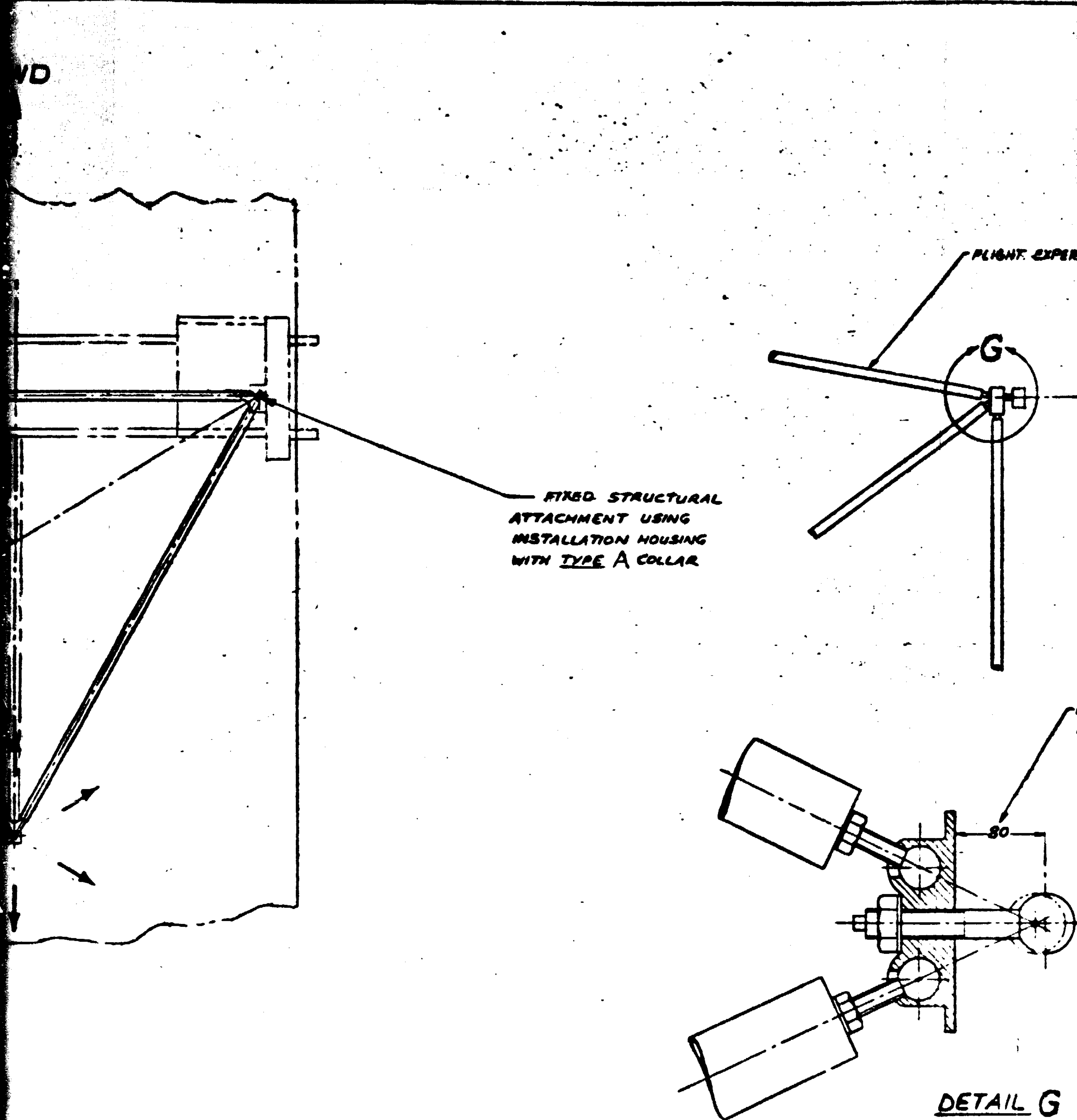


END PORT ATTACHMENT LOCATIONS

SCALE 1/20

5 FOLDOUT FRAME



ENT LOCATIONS

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DETAIL G

SCALE: 1/2

TYPICAL INSTALLA

OF STRUT ASSEMBLY

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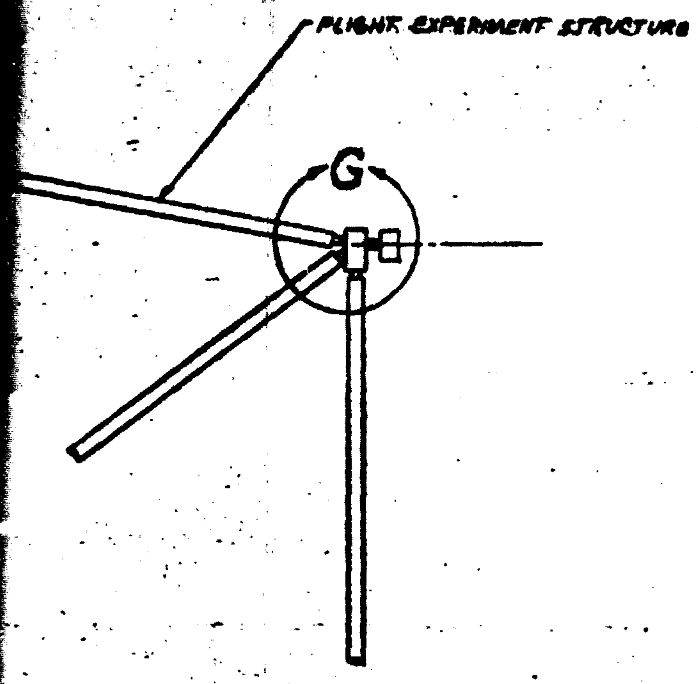

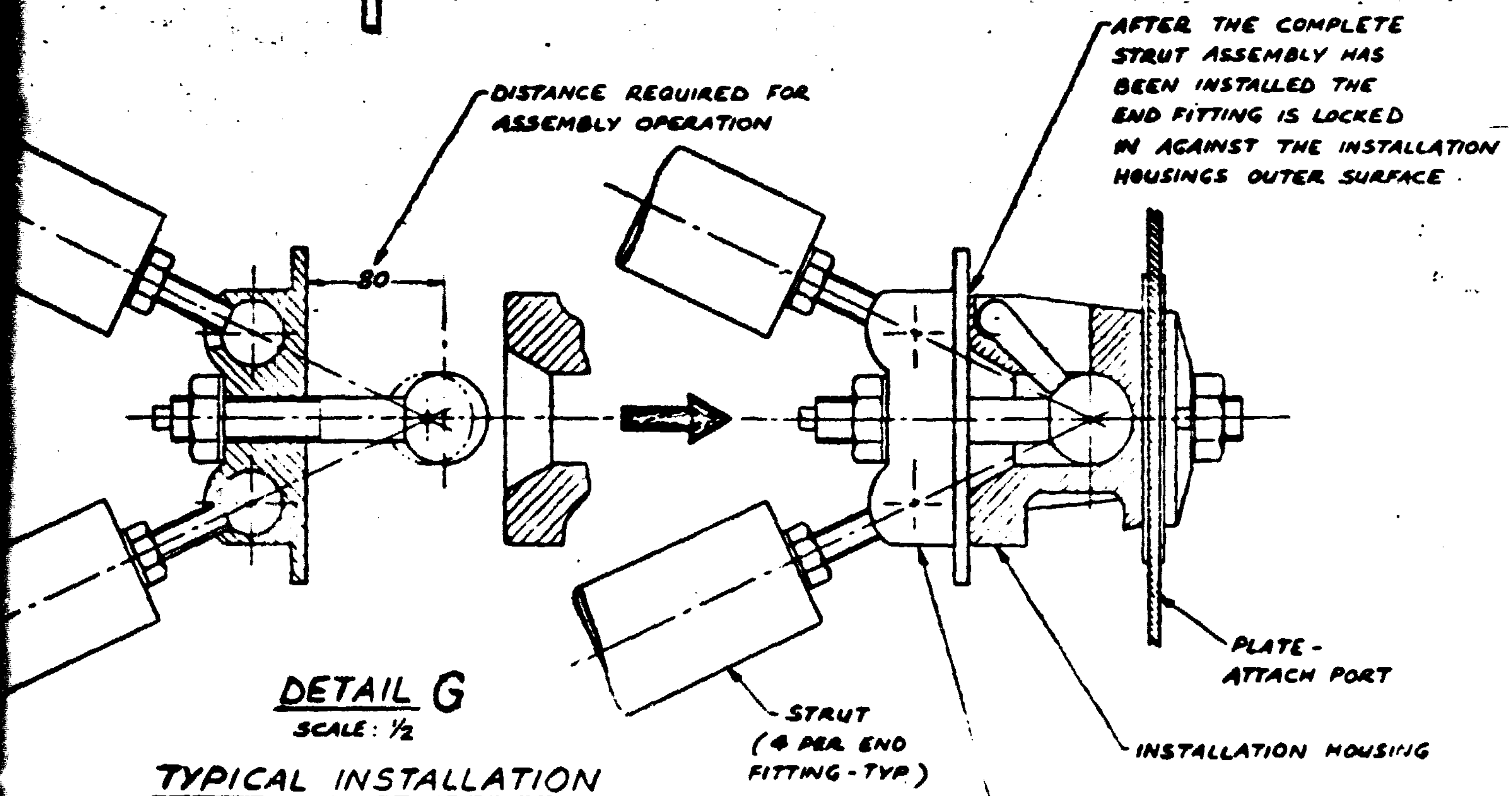

DETAIL G
SCALE: 1/2

TYPICAL INSTALLATION OF STRUT ASSEMBLY TO ATTACH PORT

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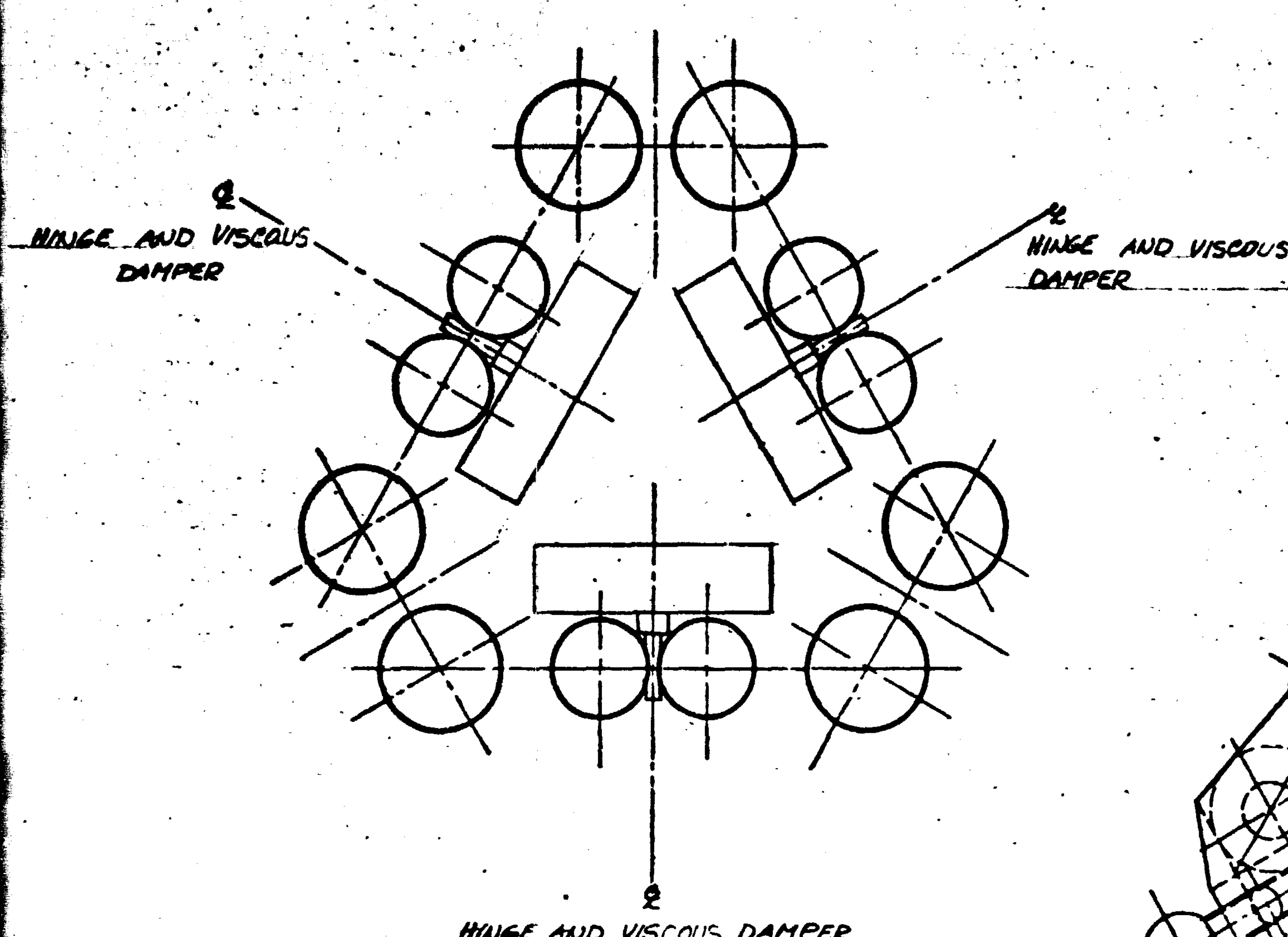
Figure 7-3.

Rockwell International	
FLIGHT EXPERIMENT STRUCTURE AND SUPPORT HARDWARE	42662-70 SHEET 3 OF 3



SECTION D-D

SCALE: 1/2

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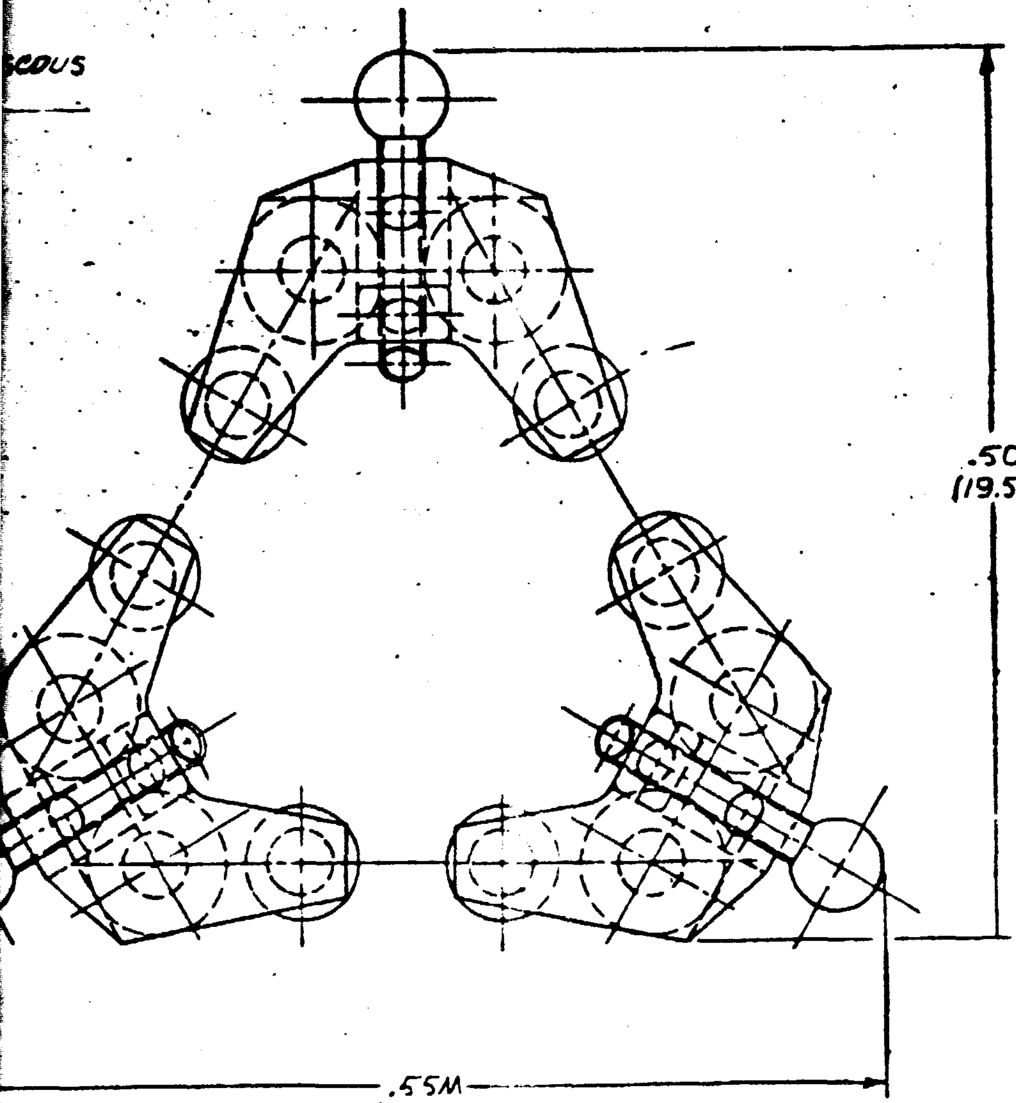

VIEW C-C

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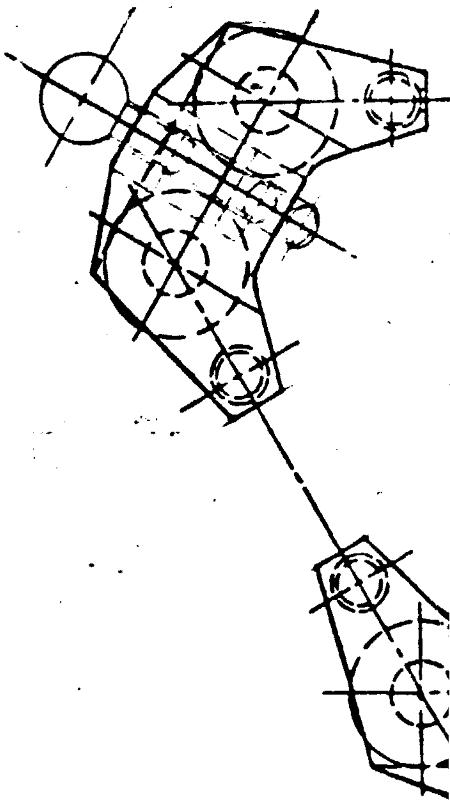

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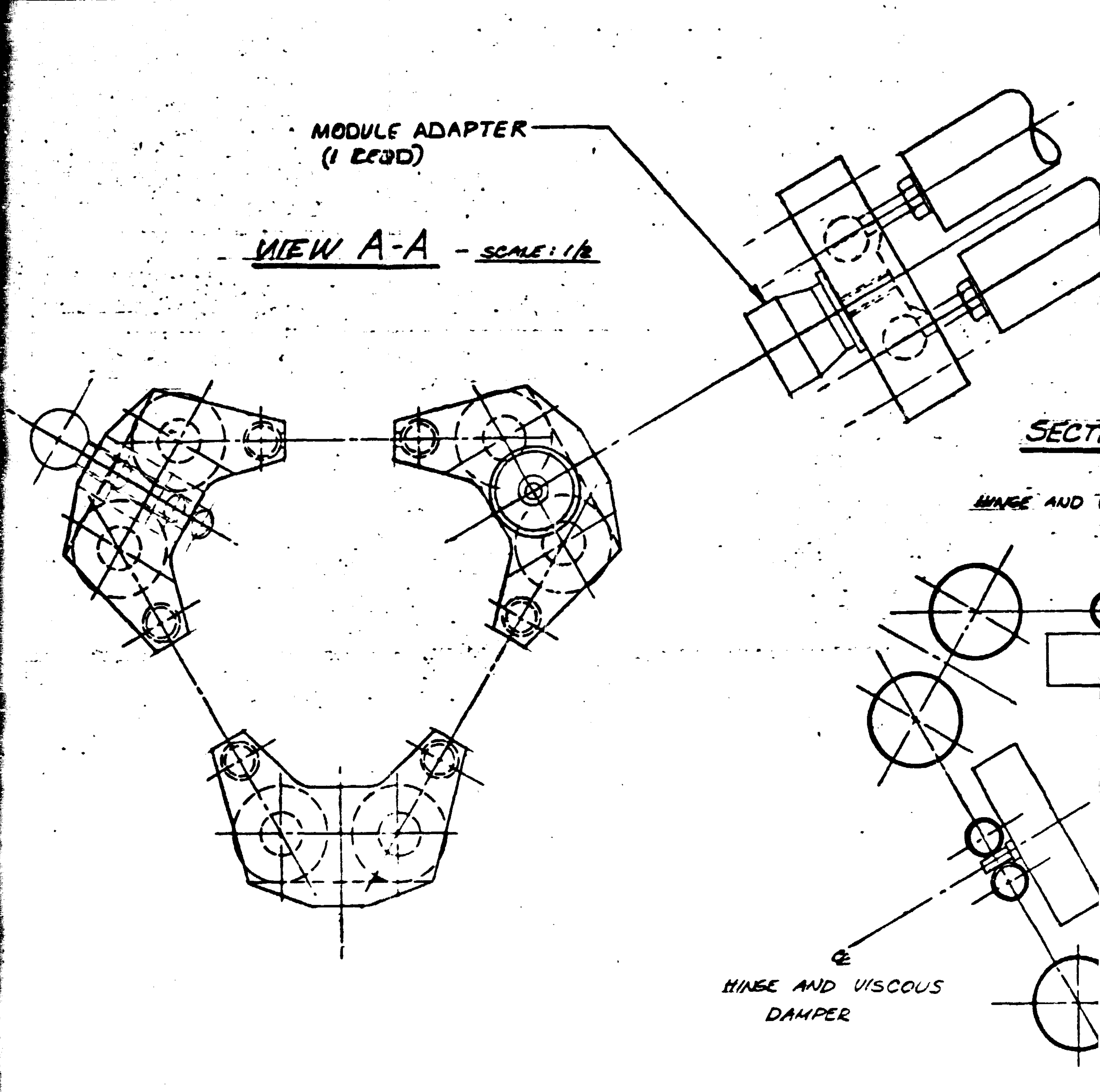
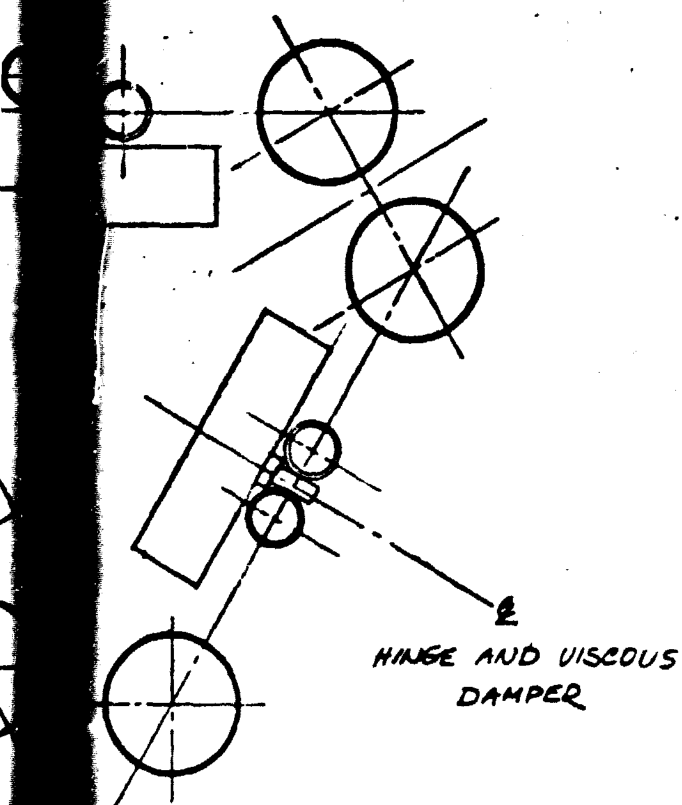
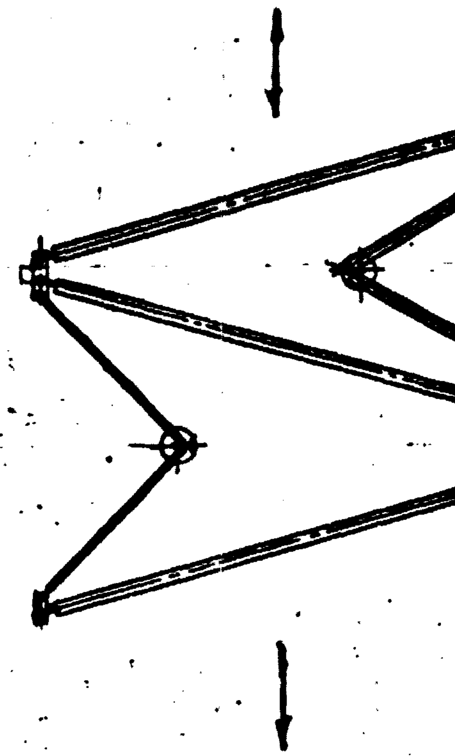


3 FOLDOUT FRAME

B-B - SCALE :1/2

US DAMPER





STRUT DURING UNF

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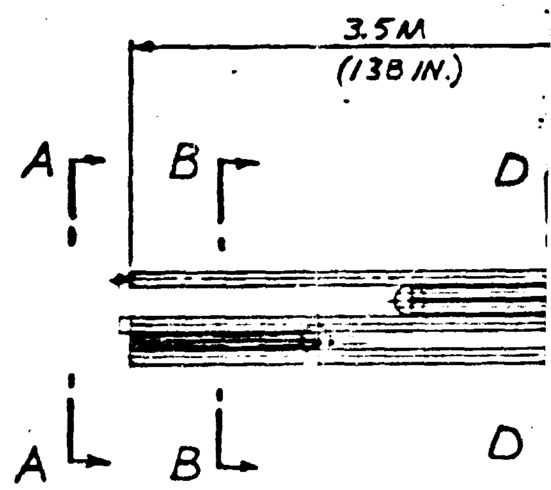

FOLDED STRUT ASSEMB

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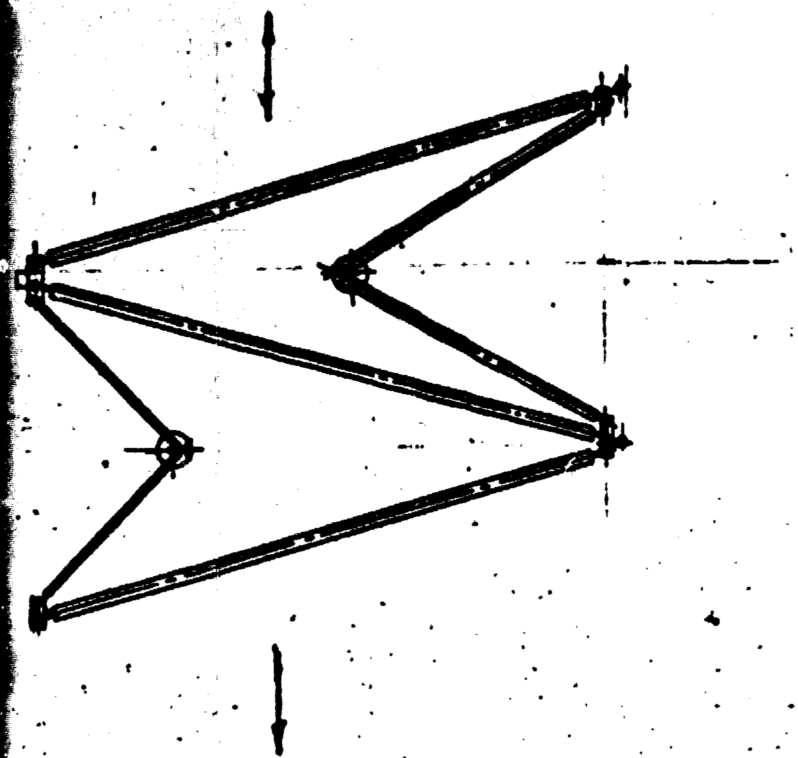

STRUT DURING UNFOLDING

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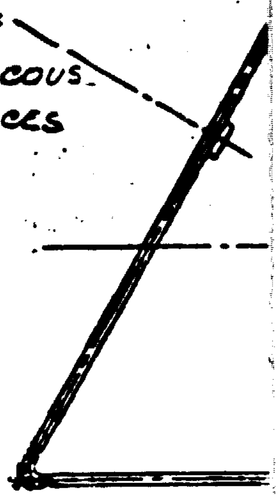
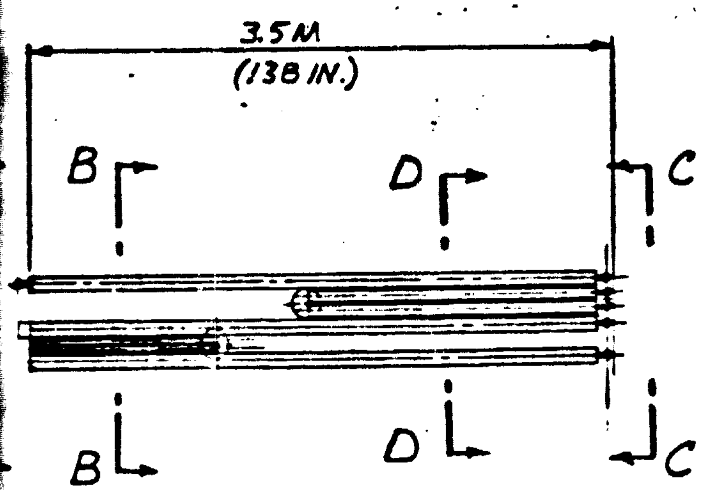
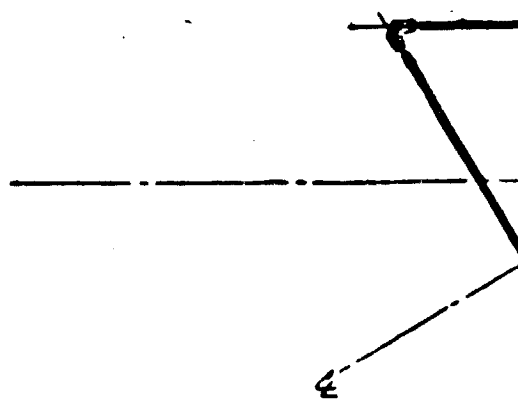




OLDED STRUT ASSEMBLY

CALE : 1/20



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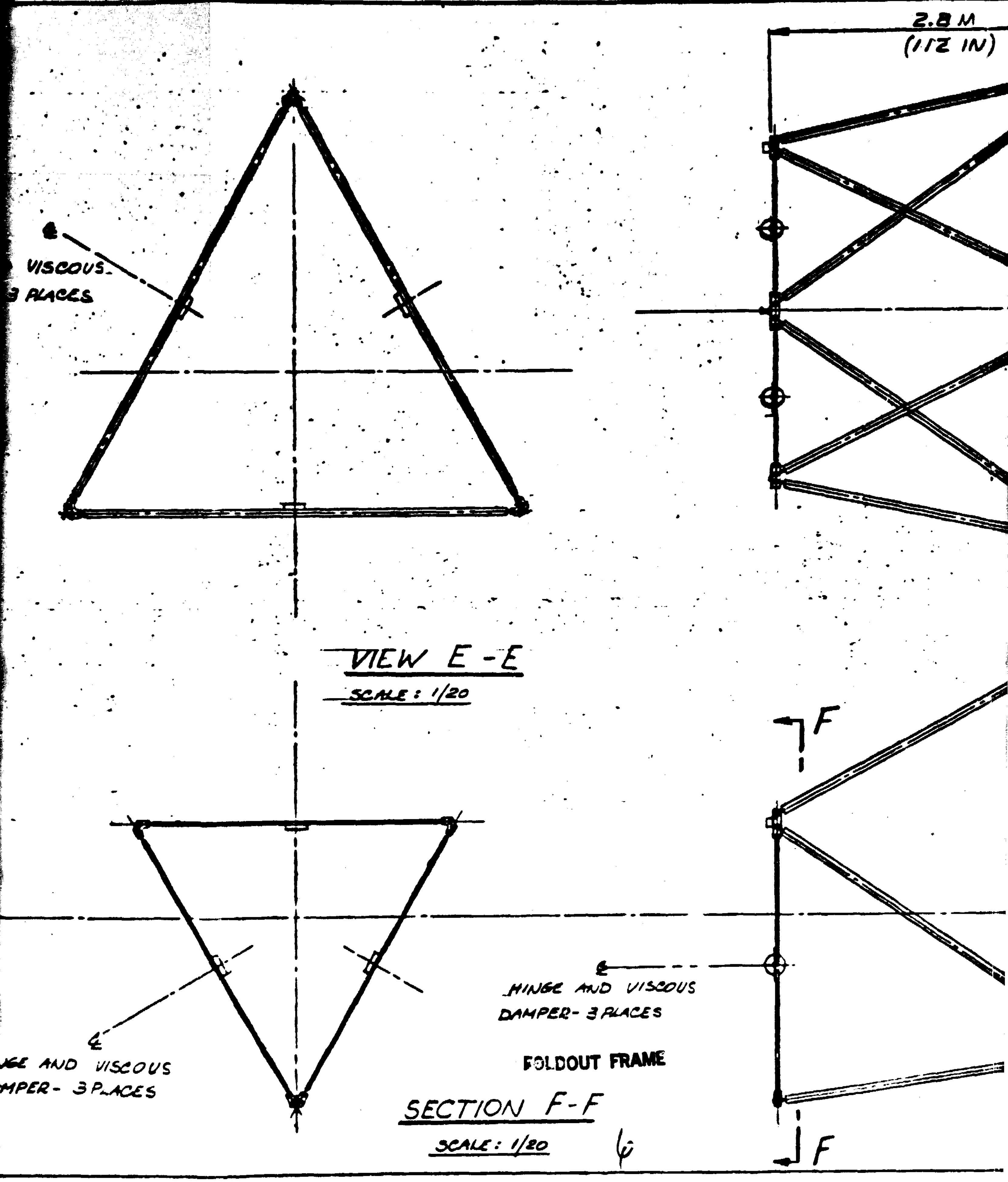

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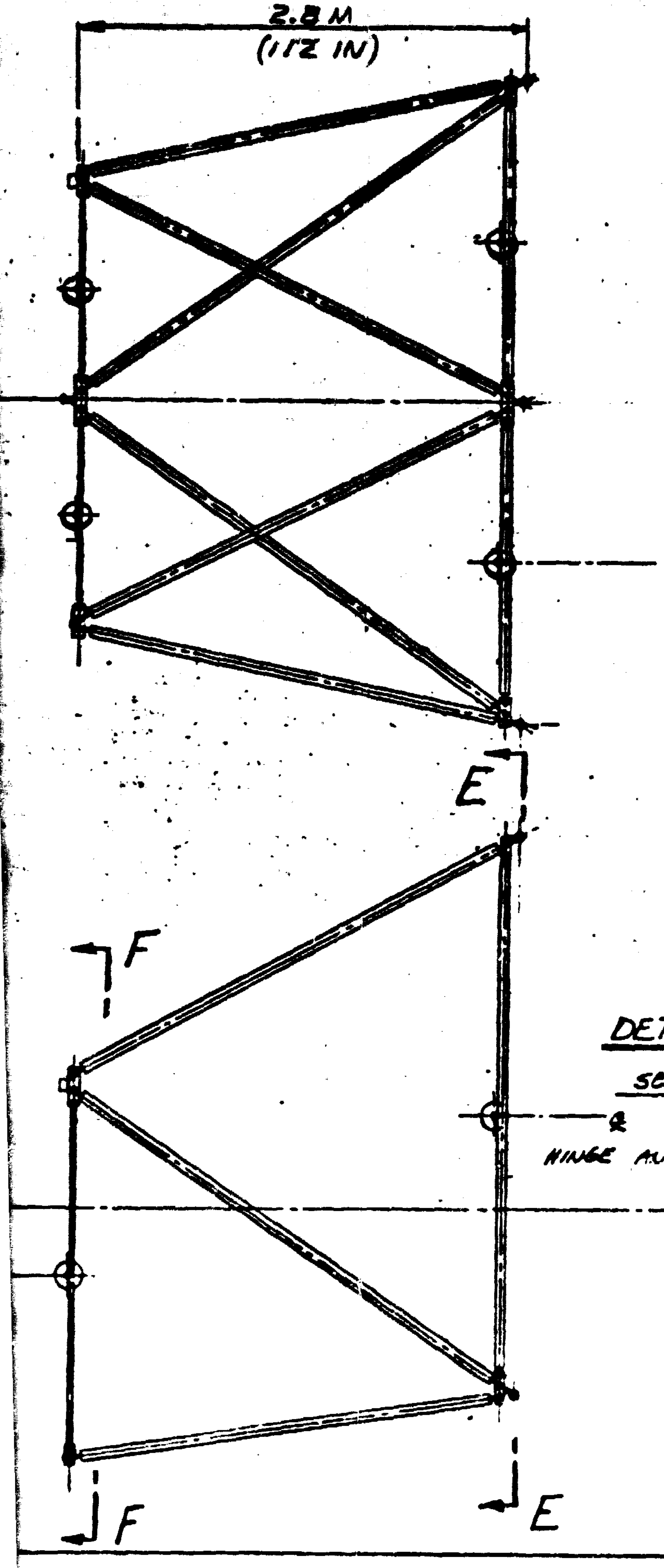


DETAIL OF STRUT ASSEMBLY

SCALE: 1/20

HINGE AND VISCOUS DAMPER- 3PLACES

1 FOLDOUT FRAME

...OUT FRAME

SHT 2 OF 3

Figure 7-3.

Rockwell International	
FLIGHT EXPERIMENT STRUCTURE AND SUPPORT HARDWARE	42662-70

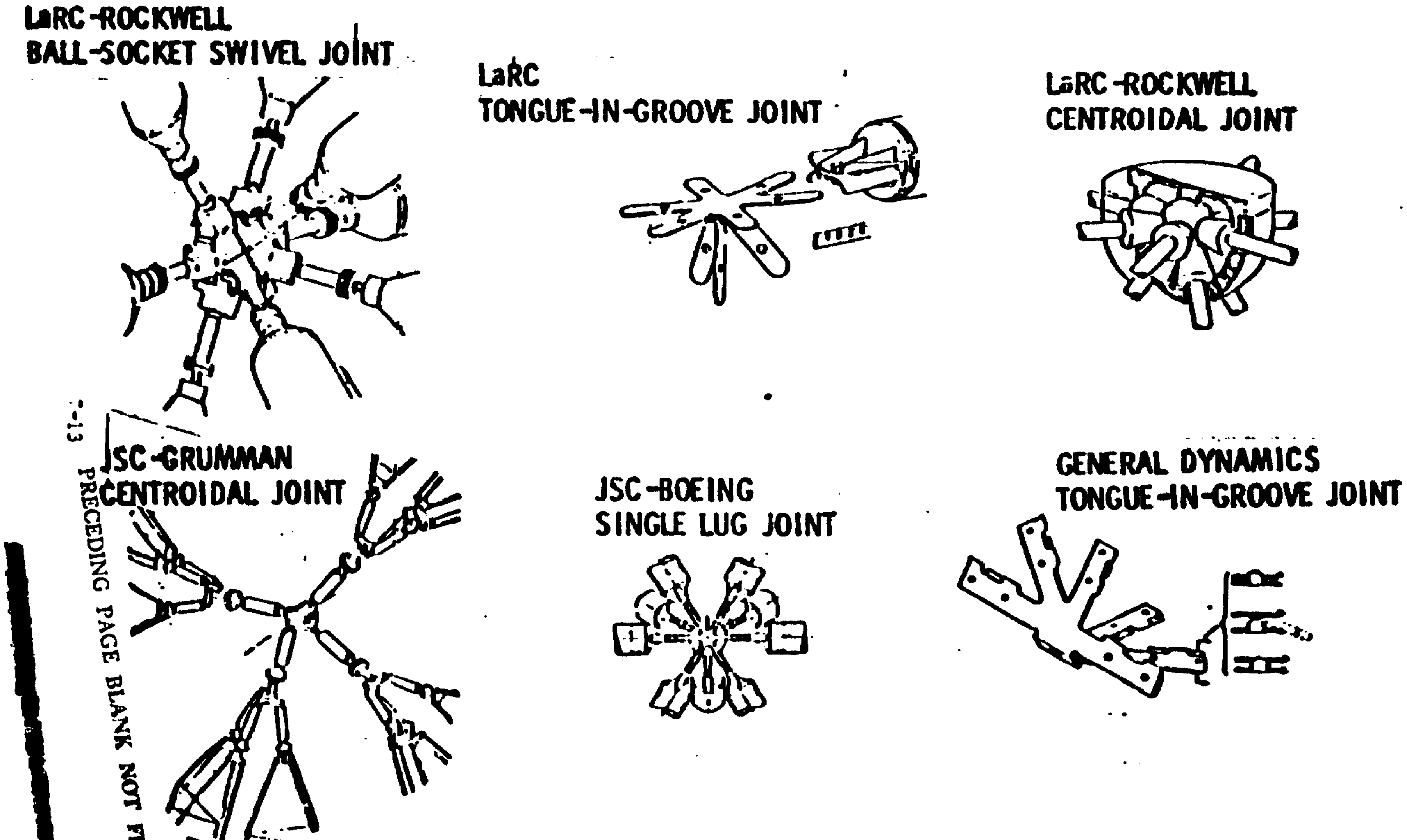


Figure 7-4. Various Joint Concepts

Figure 7-5 clearly shows the engagement procedure of the strut fitting with the socket. The ball and spherical opening provides allowances for angular and positional mismatch during the engagement procedure. The ball end which is attached to the strut is contained in the joint by means of a spring loaded latch that engages the ball upon insertion - limiting the linear motion of the strut while allowing angular displacement as required. A provision will also be provided to lock the joint(s) by means of a lock nut as deemed necessary for testing. A magnesium alloy or molded plastic will be used for the main joint body and latch if possible with the ball end material TBD. The materials will be selected for damping characteristics, strength, stiction, and compatibility with the test parameters as they are defined. The ball end to strut interface consists of a threaded shaft for length adjustment due to tolerance build up. Lock nuts can be provided to lock the joint and prevent angular motion if required for test purposes.

Removal of the strut from the union can be accomplished by depressing the trip latch either mechanically or electrically.

This joint concept has been successfully tested at NASA/JSC using the RMS simulator to effect positioning and joining operations using the RMS as the space construction assembly tool. These joints have been used for the deployed structures module and the multi-point attachment fittings connecting the structures module to the test fixture.

Large structure modules used in space construction would be required to hinge their extra-long struts in order to achieve a compact form when the module is folded up ready for stowage. Therefore, in this test module there are six center hinge joints (Sheet 2, Figure 7-3).

A latch lock hinge joint system (Figure 7-6) can be used at the mid-points of the base and top of the structure. A series of spring loaded latches will engage the mating ring upon closure of the hinge - locking the struts together. The hinge itself is spring loaded and is the driving force for deployment of the entire structure.

The baseline hinge will employ a positive engagement force hinge spring with a viscous damper to prevent undue shock to the system during the latching operation and preventing any possible kick-back in the structure that could prevent proper latch engagement. This center hinge concept has been successfully tested under simulated zero-g conditions in MSFC's Neutral Buoyancy Simulator (Reference 7.2). Due to the requirement of retrieving the test structure and returning it for post-flight ground examination, the center hinge has to be unlatched during the space experiment. Unlatching of the hinge joint is accomplished by a ramped latch release ring which, when rotated by a lanyard, disengages the latches allowing separation of the mating rings. Providing pretension with the restowing take-up reel allows the hinge to separate without continuous tension on the latch release ring lanyard. The baseline design will allow the RMS with a special purpose end effector to drive the take-up reel and to pull the latch release lanyards thus completely packaging the structure for return.

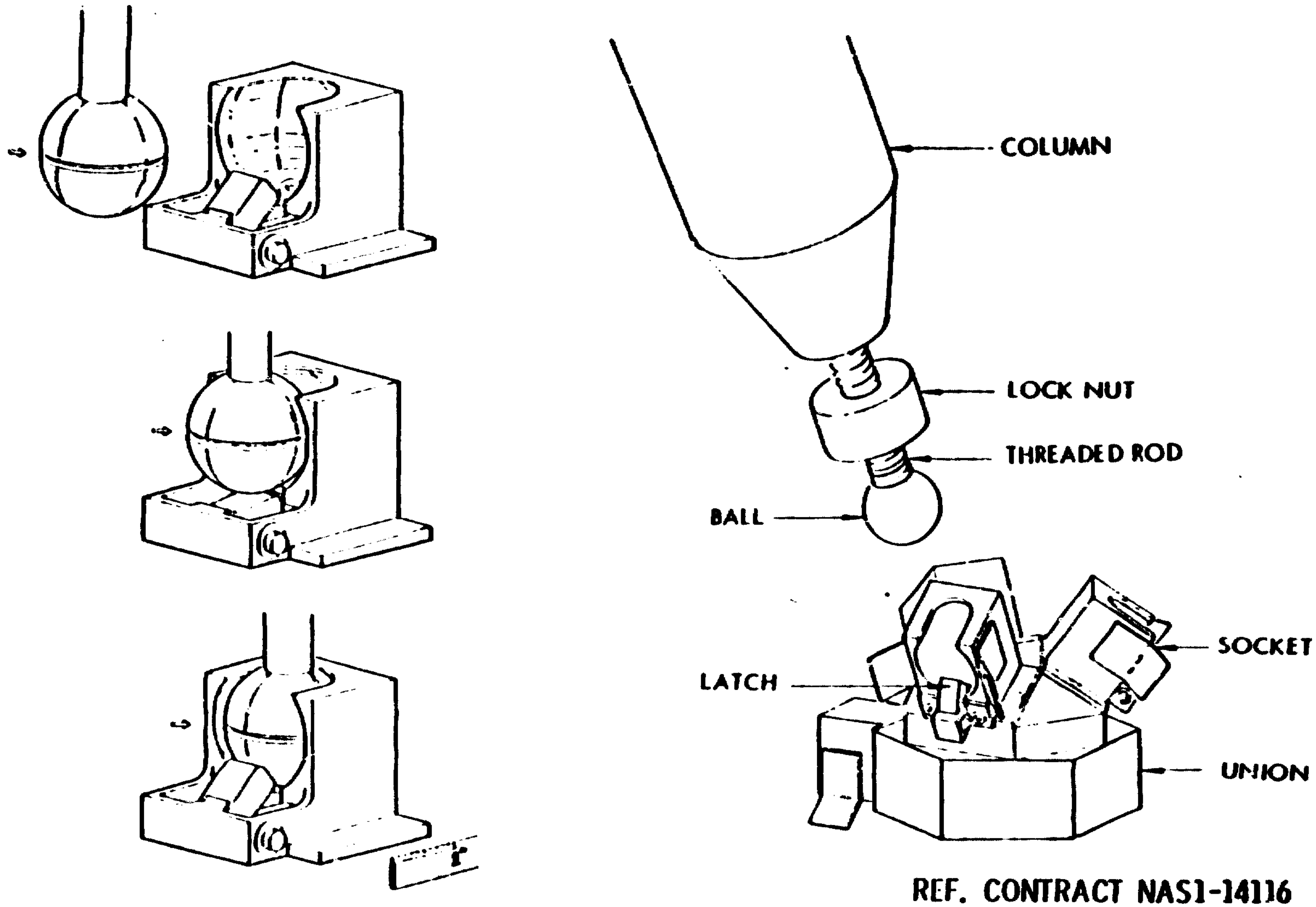


Figure 7-5. Test Article Union Ball-Socket Assembly

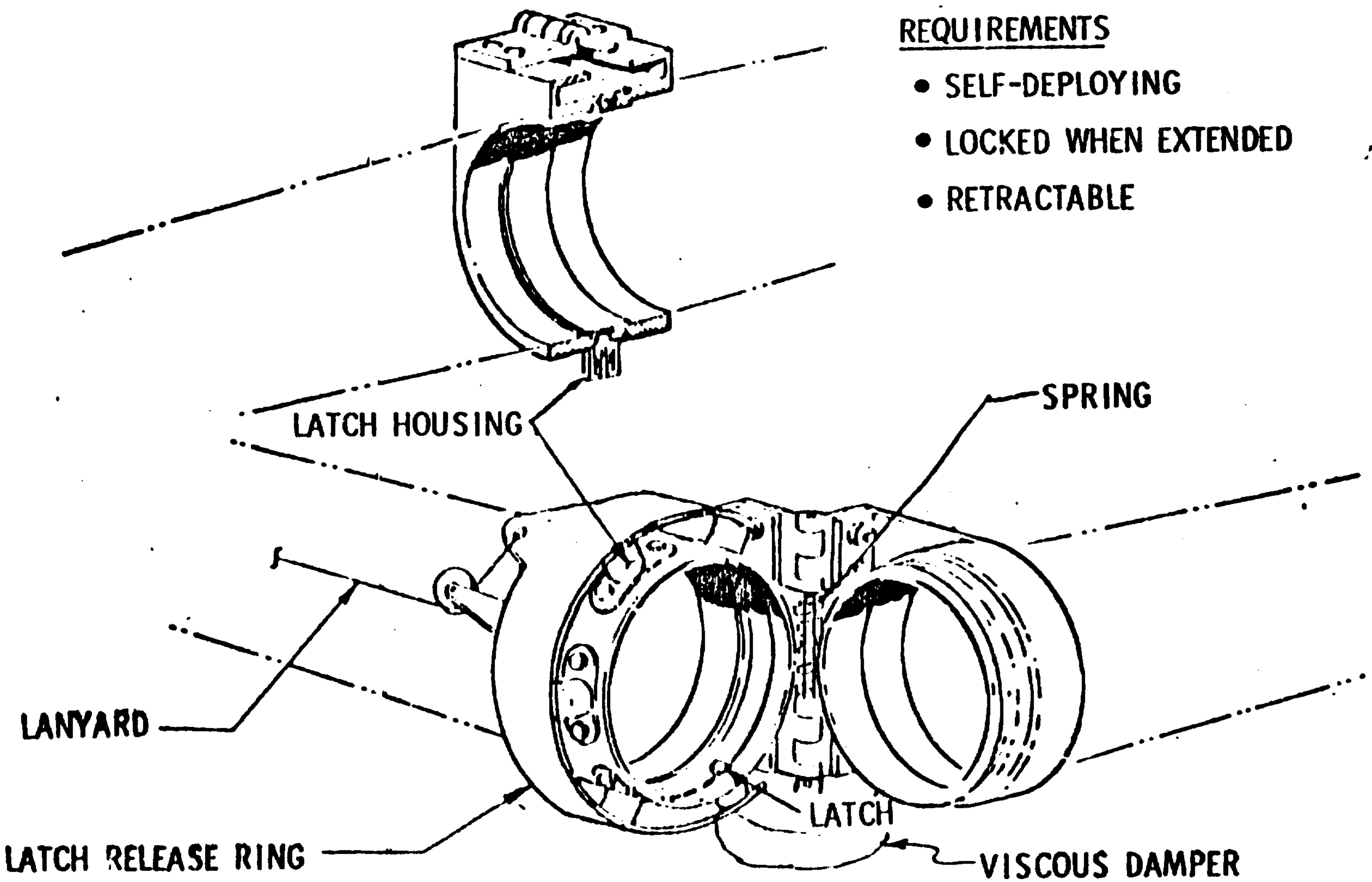


Figure 7-6. Strut Center Hinge Joint

Along with unlatching the hinge joints by means of a lanyard(s), the multiple ball joints have to be drawn together and nested for packaging in the support cradle. To accomplish this, a RMS driven reel, attached to one of the main side struts, is employed to take-up a cable that is looped through each of the three joints at one end. Separate take-up reels are provided for each end and the proper sequencing for restowing of the test structure will be determined by study of the RMS maneuvering capability in relation to the test structure stowed position. The baseline procedure will be to collapse one end, rotate the structure 180°, and reberth and proceed to collapse the other end. To prevent slack in the stowage lines, a drag system will be employed in the take-up reel for use when the structure is being deployed. During takeup, a locking ratchet mechanism in the reel will prevent the test structure from separating and will lock the structure together for stowage in the support cradle.

The baseline deployable structure module can be collapsed to an approximate 0.5 m diameter by 3.5 m long bundle that can be stowed cross-wise in the orbiter payload bay on a cradle that will also be used for a test fixture and berthing platform. Binding straps will contain the bundle until deployment is desired and hold down clamps will contain the bundled struts in the cradle payload container.

The three structural joints at the base of the structure module also have a single ball end attachment (Sheet 3 of Figure 7-3) that provides the passive portion of the berthing system for the test. The active half of the berthing system is mounted on the test fixture cradle and will be described later with the flight support equipment. A single ball-end attachment is also mounted on one of the upper ball joints, which is used for restraining the structure during the restowing operation.

The experiment test fixture attached to the cradle provides the three berthing fittings (Figure 7-3) for a test structure to simulated space module/platform interfaces and also provides a test fixture for the dynamic and structural testing of the experimental structure module. All berthing operations are performed using the RMS with a special purpose end effector to effect mating. This operation, therefore, does not require an active attenuation system because the contact velocities will be less than 0.1 fps. Consequently, passive solid berthing fitting on the test fixture will provide the physical attachment for the structure module.

However, due to the dimensional variations (manufacturing, assembly, deployment, thermal, etc.) that can be encountered between the test structure module and the test fixture in the orbiter, a "floating" interface will be employed at two of the three berthing ports. The initial berthing of the structure module will be to a "fixed collar" retention housing (Figure 7-7). The test structure will then be berthed to a retention housing collar that allows linear motion in the direction of the dimensional mismatch between berthing ports 1 and 2 thus accommodating the possible mismatch. The final berthing port will employ an omnidirectional floating collar, in one plane, to accommodate the mismatch it can experience due to misalignment of the previous two ports.

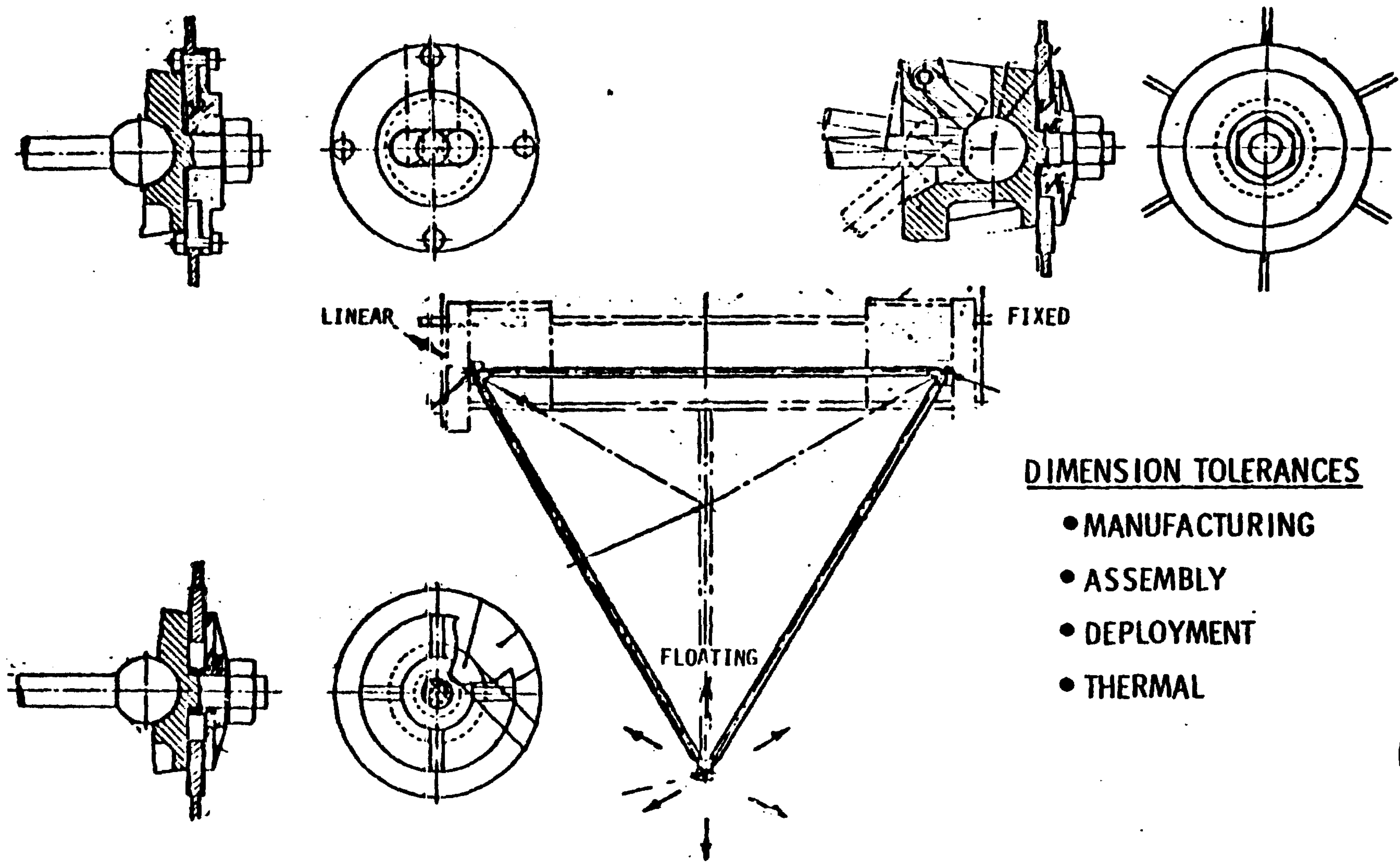


Figure 7-7. Multi-Point Attachment

The structure module is the passive half of the interface using a single ball end attachment. The active portion, that which contains the mating latches, sensors, and release mechanisms, is provided by the cradle supported test fixture. This concept permits the verification of latch operation before testing and simplifies the structural module design for packaging.

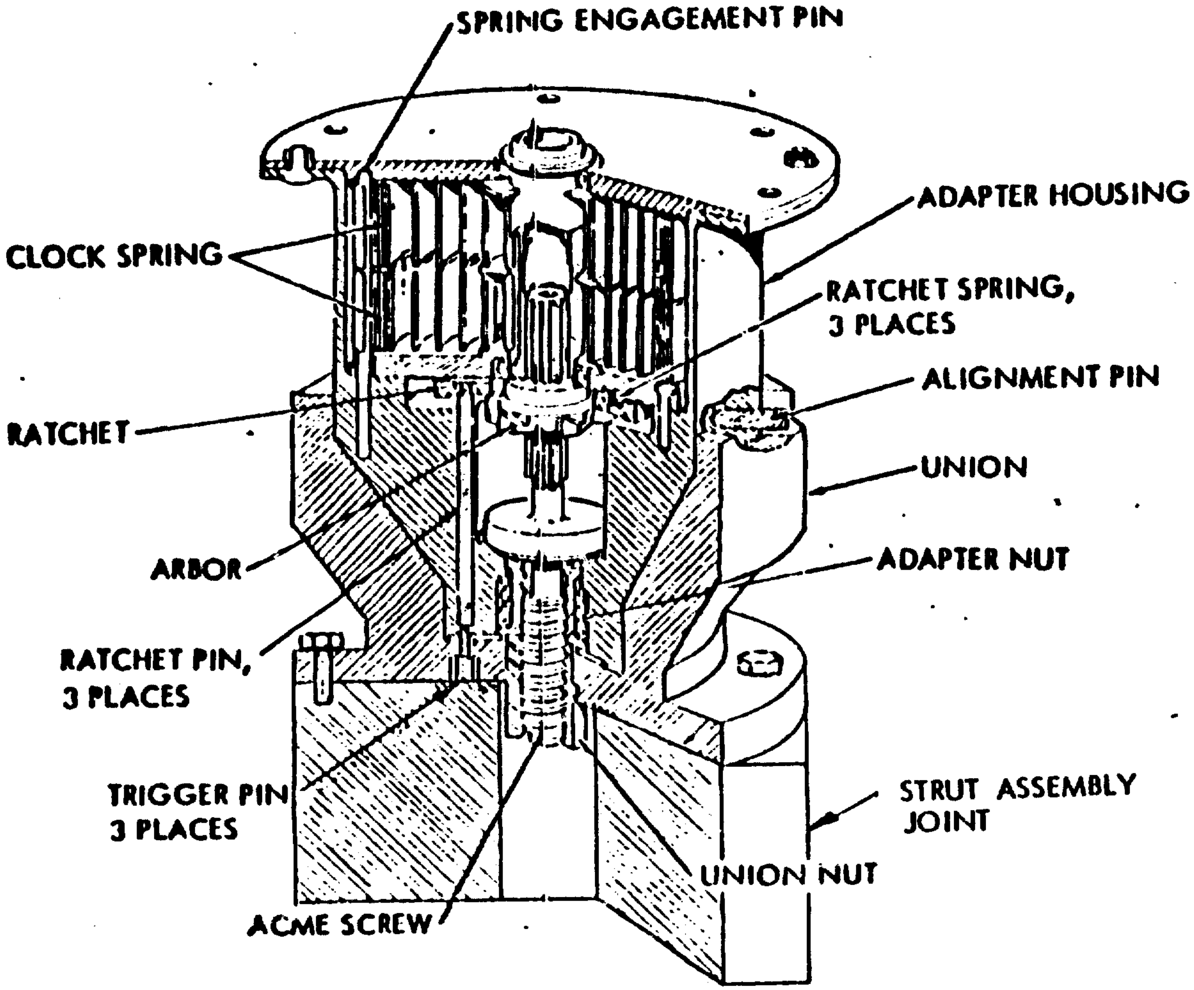
The test equipment module (shaker module) is used to provide the vibrational and dynamic forces to be induced into the test structure module. The shaker module will contain a random vibration generator besides having a modified ground test shaker for the dynamic testing. The modification will be for space qualification, i.e., use of dry film lubricants, modification for compatibilities with orbiter power if necessary, etc. The equipment will be powered directly from the orbiter by means of a retractable umbilical connected to the cradle. (The cradle having the standard orbiter/payload electrical interface). The shaker module has been designed oversize purposely so that a payload/subsystem module simulation test can be incorporated along with the structural test. Grapple fixtures and targets have been provided on the shaker module for pick-up and handling by the RMS.

The shaker module is berthed and attached to the structure module using an energized adaptor (Figure 7-8) after being delivered by the RMS. The adapter housing is attached to the shaker module and upon mating with the union that is attached to the structure, joins the two by means of a trigger release clock spring driving an acme screw into a union nut locking the system. The baseline for releasing the adapter assembly is for an EVA astronaut to unscrew the connection from the underside using a ratchet-type wrench. Depending on the special-purpose end effector design, this could be an EVA task. The design for a simulated equipment module/attachment adapter has also been tested under zero-g simulation (Reference 7.3). The electrical and signal connections are made to the shaker module with a cable "pigtail" attached to the structure module. This connection is considered to require EVA assistance for the early flight missions.

The measuring sensors are pre-attached to each end of the struts. The type of sensor will depend on the frequency and type of measurements required for this experiment. It is desirable to obtain dynamic model verification for highly flexible structures which exhibit low frequencies. The current structure module size will have a first modal frequency higher than 10 Hz which will allow low frequency Piezo electric accelerometers to be used for the vibration testing. If sensors are placed at all ends of struts connecting to the union, then measurements can be made regarding the damping behavior at that union.

The energy input will be at a single point where the shaker module is attached to the node. The form of vibration energy will be a sinusoidal-dwell-sweep or the single-point random. The single-point random could provide all the nodal data and damping characteristics required for this simple open-truss configuration.

There are several elements of flight support equipment—mechanical devices, display and control panels, wire harness, etc.—required to support the space construction experimental test operations of delivery, retrieval, deployment, testing and restowing.



- TESTED IN NEUTRAL BUOYANCY TANK @ MSFC
- MODS REQUIRED FOR EASY REMOVAL

Figure 7-8. Subsystem Module Self-Energized Attachment Adapter

The delivery and test fixture cradle provides the means for stowage of the structure module and its accompanying test equipment in the orbiter using the orbiter's standard interfaces as provided. For a listing of alternate attachment locations in the orbiter, see the table in Figure 7-3 (Sheet 1). The cradle is an aluminum tubular truss structure (Fig. 7-3) with side baskets for support of the bundled structure module. An aluminum honeycomb cover is used to support the shaker module and the special purpose end effector. The shaker module is mounted to the cradle cover using berthing latches, an example is shown in Figure 7-9. This particular latch is under development by NASA/Goddard for the MMS vehicle. The latches required for Experiment No. 2 need not be so robust as they are required to attach and restrain test equipment that weighs less than 200 lb.

The cradle used for the experiment will use the standard longeron and keel non-deployable attach fittings as provided by the orbiter (Figure 7-3). Alternate locations for the cradle have been determined and the cradle to orbiter attach points are listed also in Figure 7-3.

A deployable three-legged frame is attached to the aft end of the cradle (Figure 7-3) for support of the deployed structure module. This frame is to be deployed and locked into place with the use of the RMS. Upon completion of testing, the RMS will release the hinge locks and restow the frame.

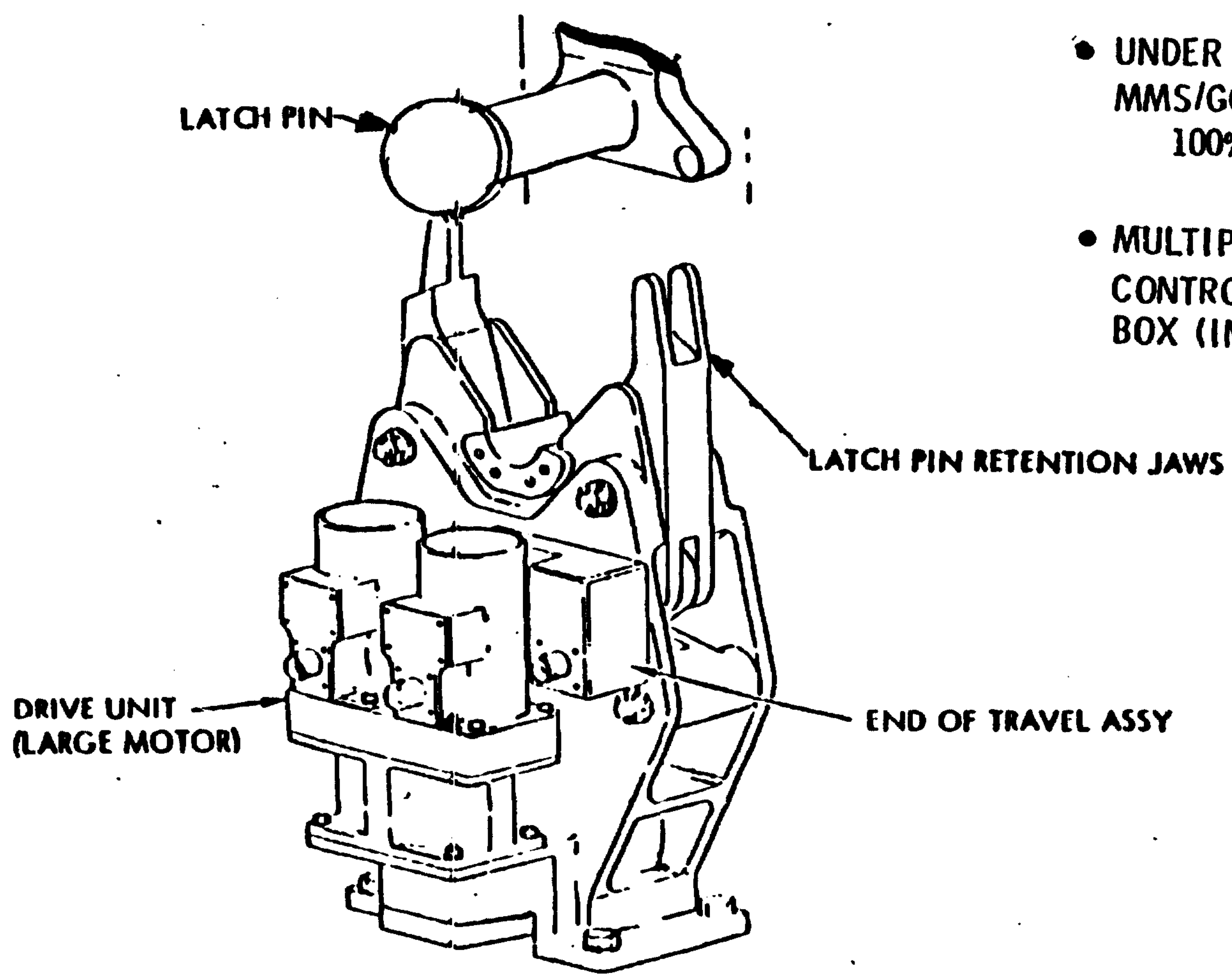
A latching mechanism of the type as shown in Figure 7-9 will be used to deploy and relatch the support frame and the cradle support cover.

The three berthing latches mounted on the test fixture are used to simulate the actual berthing conditions of a deployable truss structure.

If this experiment has to be included in a Shuttle flight that contains the Spacelab and its tunnel, then the container support structure will need to be modified. With the cradle placed in the forward section of the bay, the cradle will straddle the tunnel, Figure 7-10. The support structure to the keel fitting is designed to clear the tunnel envelope and will be installed after the tunnel is in place. The down support struts are detachable and will be placed around the tunnel and bolted to the container and the keel fitting.

Due to the rear of the tunnel sloping upward, the rear attach point of the test fixture in its extended position will be higher than previously defined. Figure 7-10 shows how the rear strut and its bracing struts clear the tunnel structure. The interface plane where the structure module is berthed will be above the cargo door sill. The top center strut to this rear attach point will be hinged and the two lower struts simply rotate about their bottom fittings.

The RMS operation for the space experiment mission will be involved with various types of construction operations and is required to handle different structural forms. Basically there are two distinct problems which must be considered with respect to the design of Experiment No. 2:



- UNDER DEVELOPMENT FOR MMS/GODDARD
  100% DRAWING RELEASE
- MULTIPLE LATCHES CONTROLLED VIA RELAY BOX (IN DEVELOPMENT)

Figure 7-9. Example Berthing and Restraining Latch—Disengaged

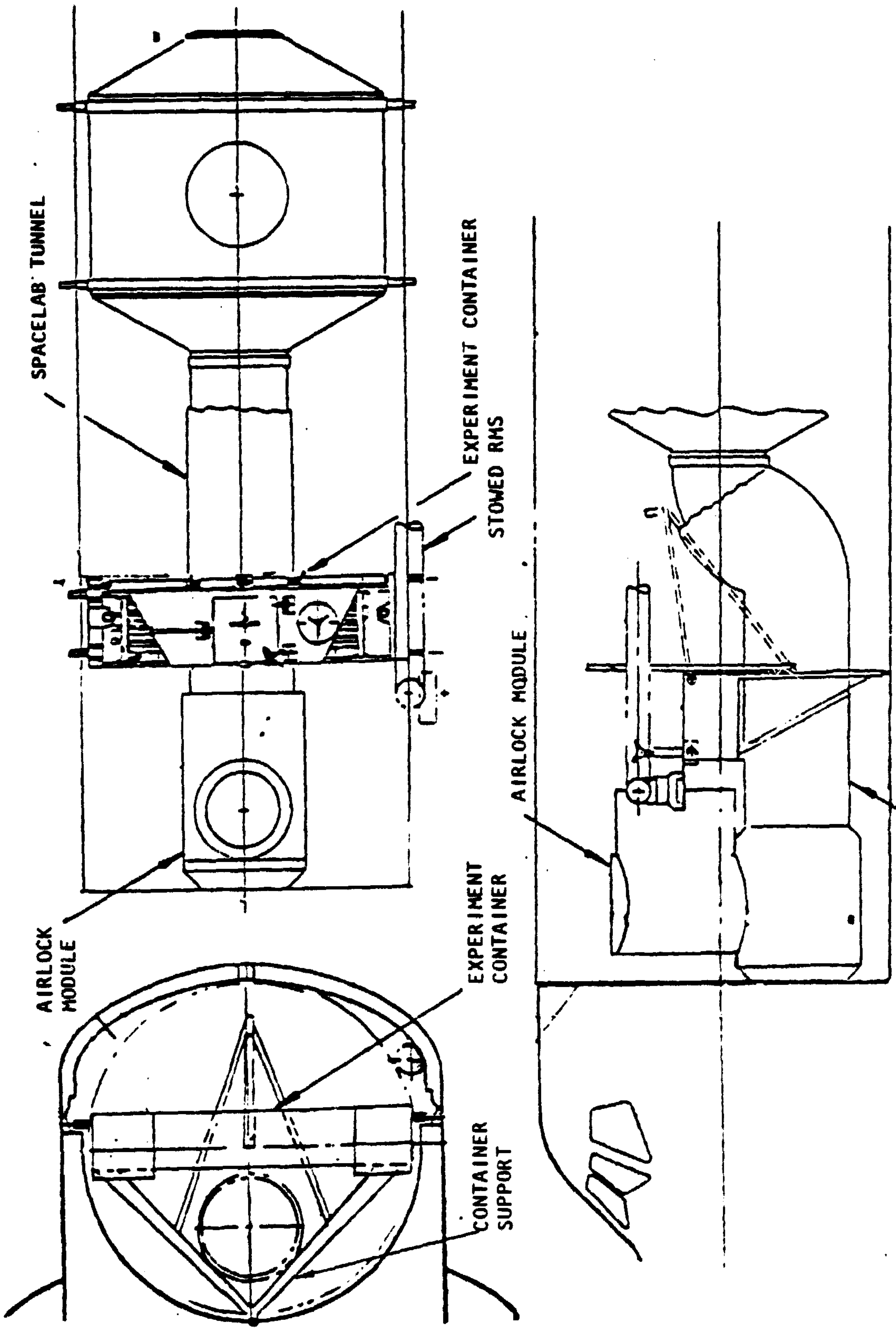


Figure 7-10. Experiment Installation with Spacelab in Cargo Bay

1. Docking of an object grasped by the RMS to a second object and viewing for the second docking.

2. Docking the RMS end effector with different elements, ranging from tubular struts to large diameter modules.

It is recognized that the RMS end effector design is not part of the study objectives, but an understanding of its requirements for space construction is necessary. It will affect the design details and the operational procedures.

The obvious choice is to employ the current RMS end effector with the standard grapple fixture and target (Figure 7-11). The approach viewing of the target is via the wrist mounted CCTV camera. When the first objects' target has been successfully engaged by the end effector, the target and its scuff plate will obscure the major portion of the CCTV field of view and block the viewing of a target on the second object. For example the RMS will be required to dock with the shaker module and then transfer this module to the top structural node of the deployed struts. If the first target grapple is placed on the side of the shaker module at the interface of the module side with its bottom surface, then the CCTV camera will be unable to see underneath the module for subsequent docking with the structural node. Since the CCTV camera is mounted on the wrist, the target cannot be rotated out of the field of view of the camera. Therefore it will be difficult to adequately view the second target.

There appears to be a need to remove or reduce the target image from the CCTV screen prior to the second docking operation. Two approaches suggest themselves to reduce the field of view blockage. One is to have an end effector which does not require this grapple target and the second approach is to leave the target behind after the first grappling operation.

If we consider the second alternative, the grappling of the shaker module stowed on top of the canister, the target and the lower half of the scuff plate would be attached to the canister immediately adjacent to the attachment point of the shaker module. After the shaker module has been released from the canister and moved to the structural node, the underside of the module can be clearly viewed via the CCTV screen. This will allow alignment of the module over the structural node in two directions with respect to the RMS end effector. The depth perception gauging to ensure aligning the module probe above the node opening will be achieved by visual cueing and/or a back thrust plate. One of the key test objectives is to demonstrate the RMS's ability to attach payload modules to typical structural nodes.

The removal of the shaker module after the experiment will be with the RMS attaching to the same grapple, but the CCTV will be viewing another target on the module itself. After docking with the module and removing the module from the node, the RMS wrist camera will have a limited field of view. The final stowing of the shaker module into the container will be accomplished via the CCTV camera within the orbiter's cargo bay and viewing from the aft window.

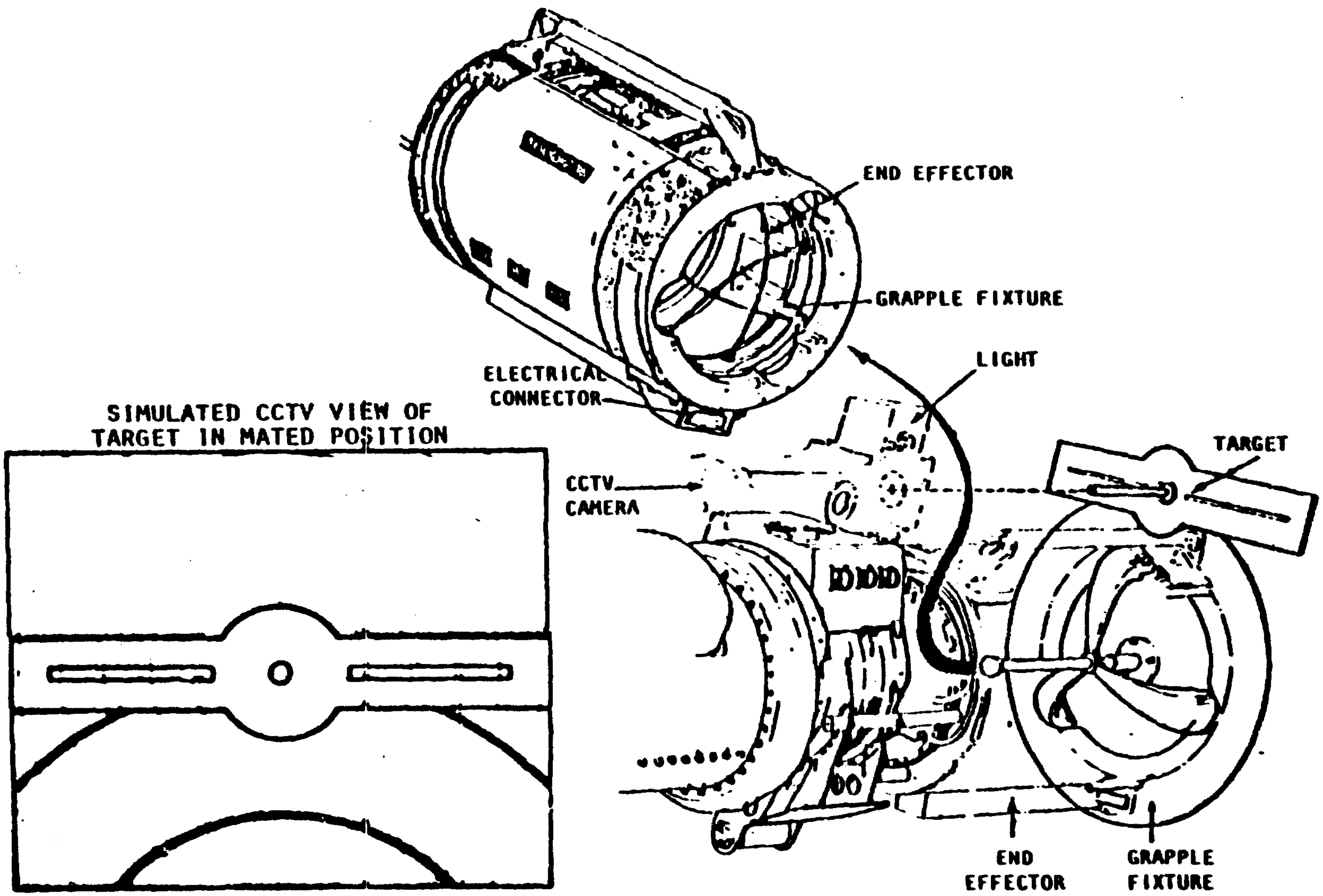


Figure 7-11. End Effector/Grapple Fixture Interface

The multipoint attachment of the structure module to the test fixture requires that the RMS camera can view the attachment fitting into which the RMS is required to place the ball-fitting attached to the structure module (Figure 7-12). A marking placed on the lead-in guide of the thrust place would aid in range estimation and alignment.

The method of grappling with the standard end effector is not the most effective way of picking up small and irregular shaped objects. This experiment must extract the stowed struts from their container and install the node fittings of the deployed structure into their respective berthing attachment fixtures. The basic requirement is to grasp the cylindrical struts at the ball socket unions. An effective way of performing this operation would be with an end effector concept similar to that shown in Figure 7-13 which has been suggested by Rockwell in previous large space structures studies. The three-finger end effector built at NASA/JSC (Figure 7-14) is another end adapter that is capable of grasping various shaped objects. Reference 7.4 has considered a class of various types of end effectors (Figure 7-15) and has evaluated their relative effectiveness for space construction applications including struts, unions (joints) and mission equipment (Table 7-3).

7.1.2 Mission Scenario

This experiment is concerned with two distinct areas: first is the aspects of deployment and construction; the second is the effect of dynamics relating both to the structures response characteristics and interference with the construction operations. There are various times in the overall mission scenario where differing types of experiment objectives are verified. In fact several operations are repeated to obtain statistical data on the operational procedure and to investigate the effect of external disturbances (lighting, motion) on the operational timing.

The total mission has been divided into eight major operational tasks. These tasks are identified below:

1. Preparing RMS for operation
2. Release and unpacking of experiment container
3. Release and deployment of structure module
4. Installation and activation of shaker module
5. Dynamic experiment and measurements
6. Module release, translation and redocking
7. Experiment breakdown and restowing
8. RMS shutdown

Each of the eight major operational tasks is composed of a series of repetitive operations using the RMS, EVA astronaut, or remotely actuated mechanisms. The actual division of operations between the EVA astronaut (manual) and the RMS (automated) still remains to be identified. The fully automated (remotely activated) operation demands a higher degree of equipment complexity and, hence, higher development and fabrication costs. It is possible that major

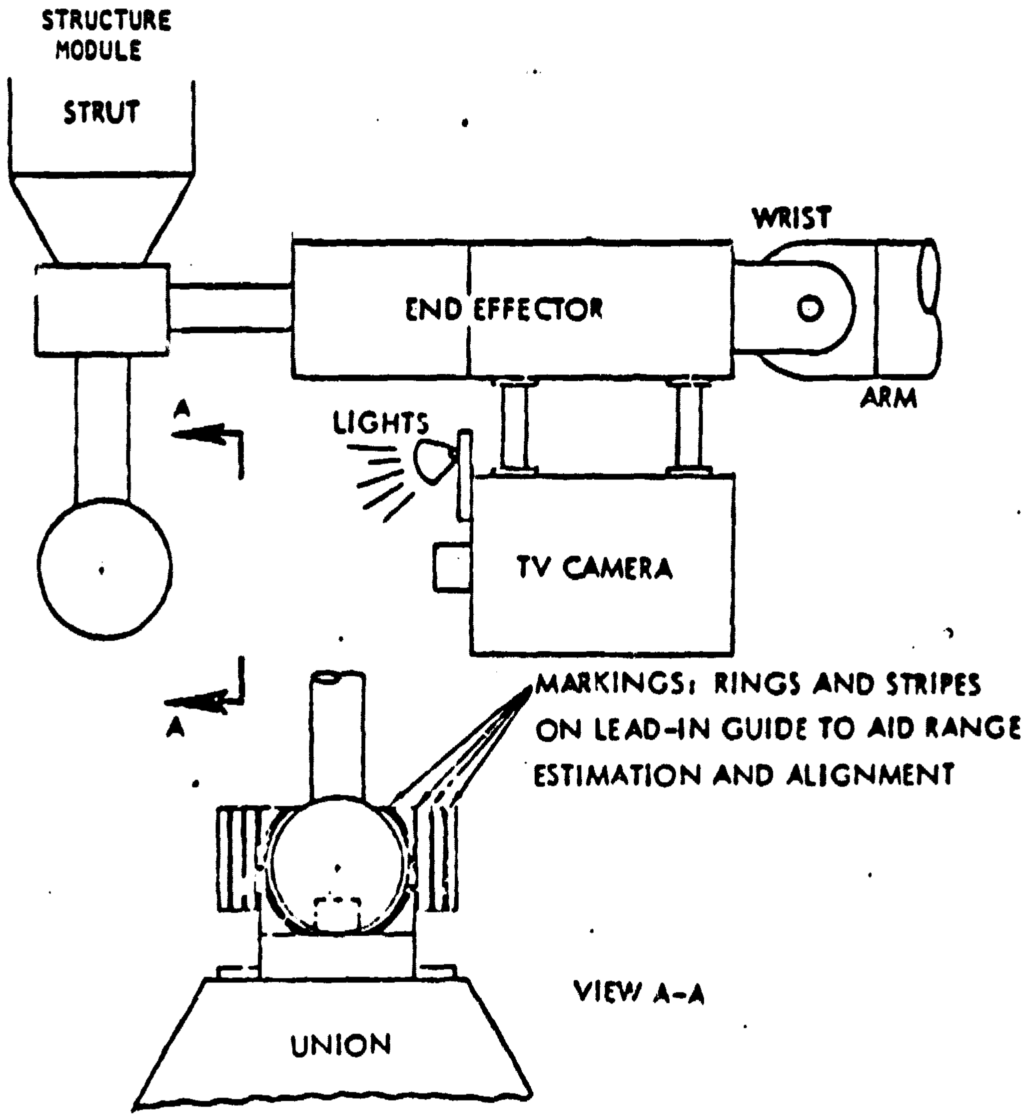


Figure 7-12. Target Viewing for Multi-Point Attachment Fittings

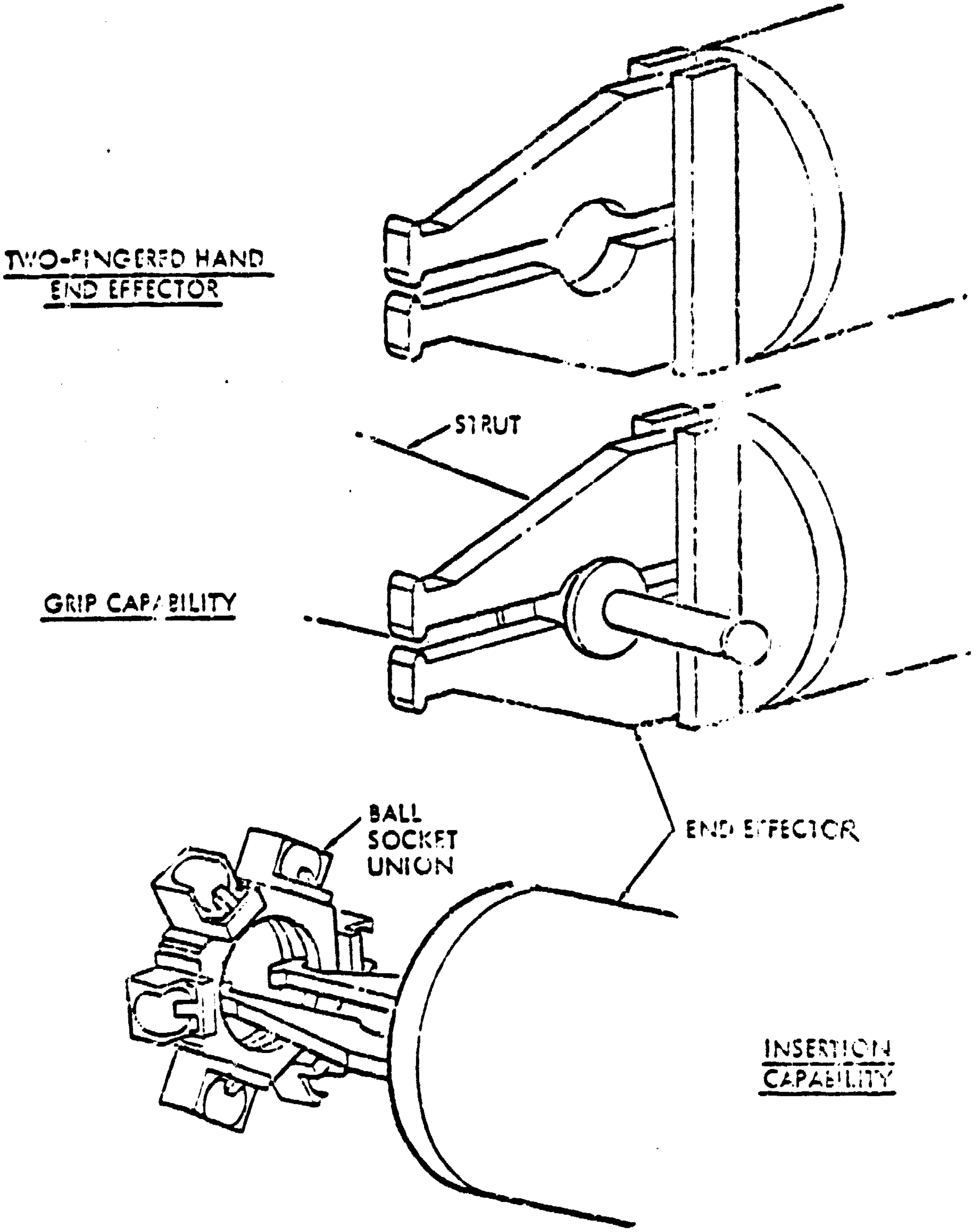


Figure 7-13. Typical End Effector Concept for Handling Struts and Unions

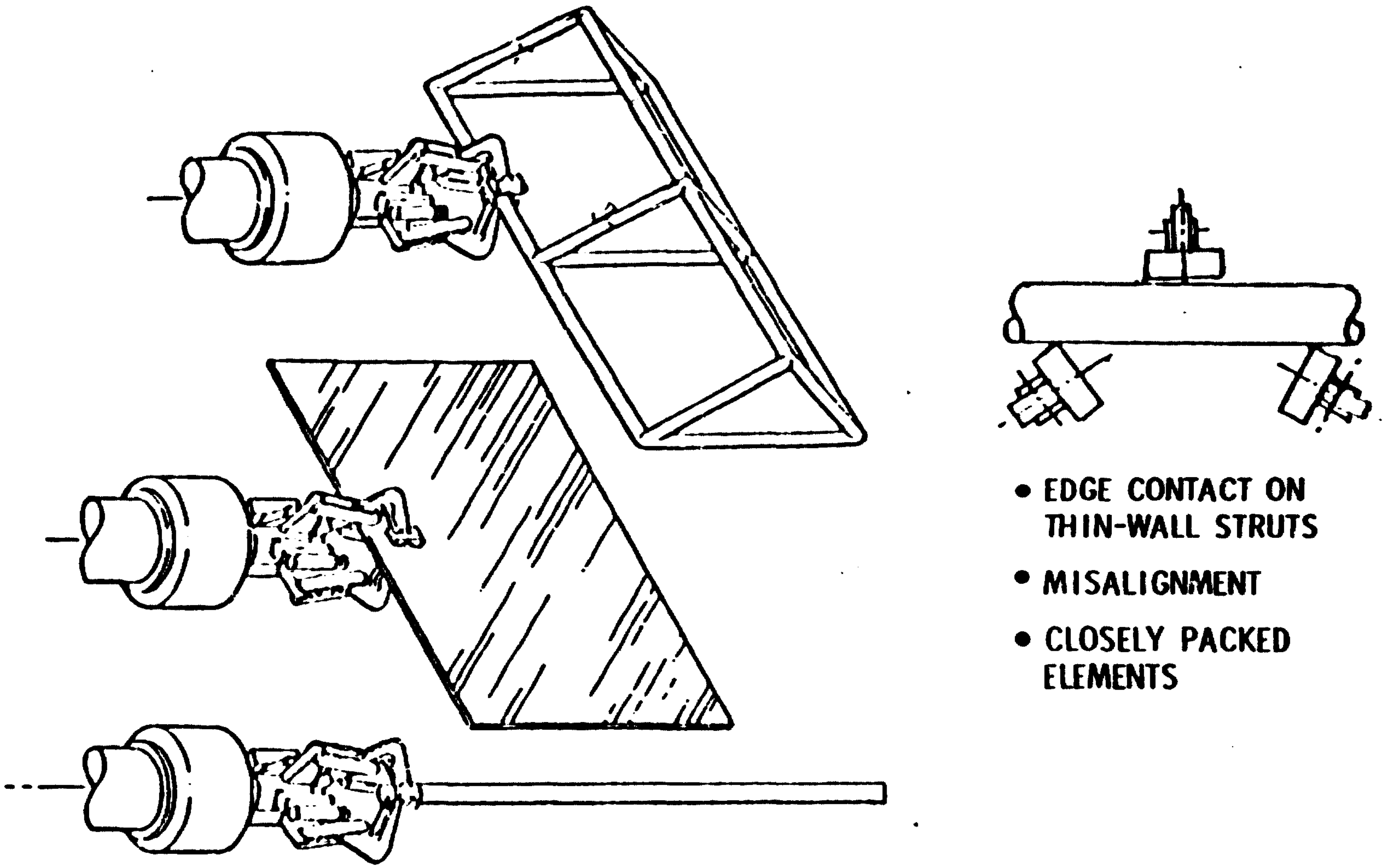


Figure 7-14. JSC Three-Finger End Effector

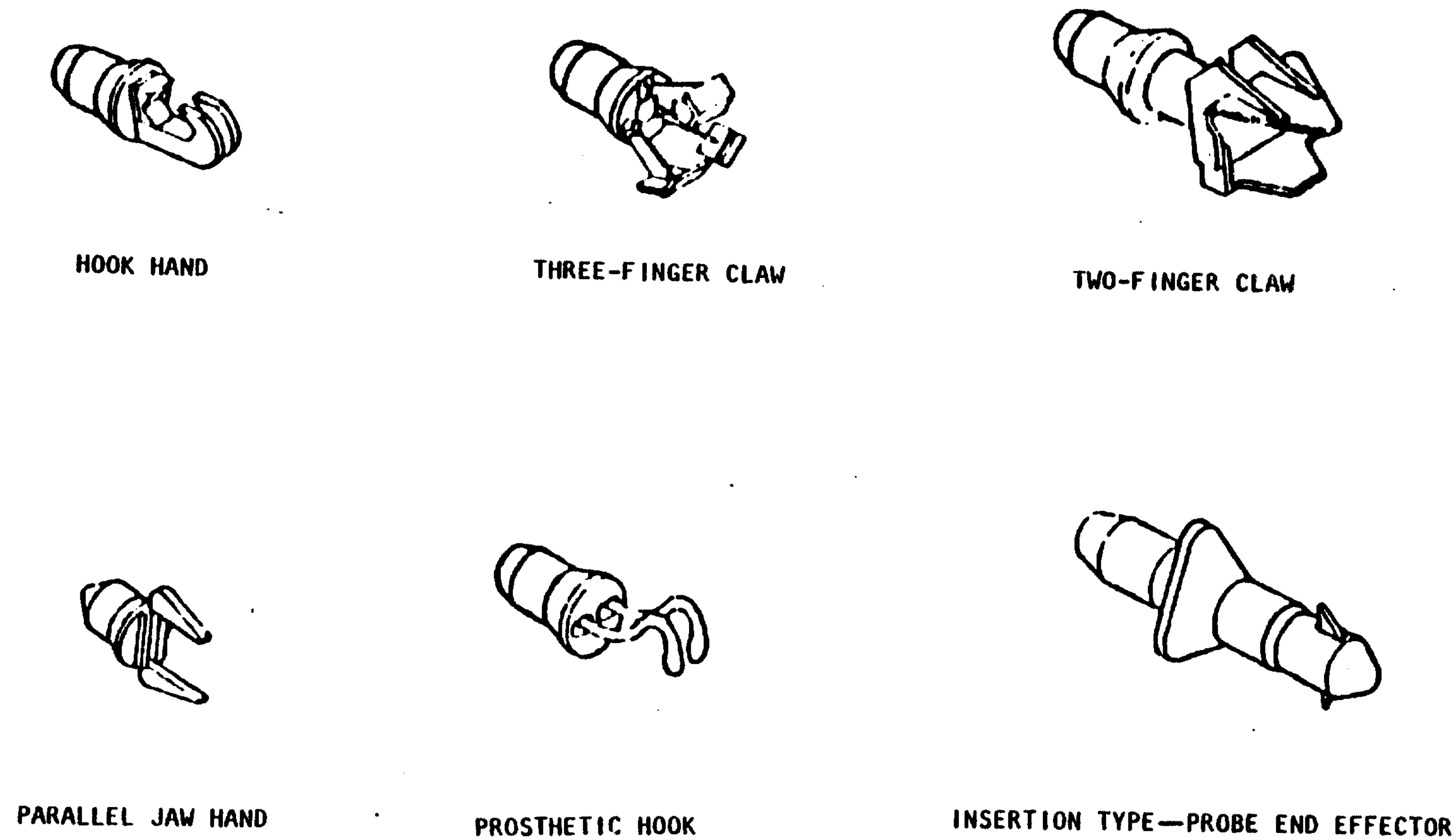


Figure 7-15. Classes of End Effectors

C-2

Table 7.3. End Effector Evaluation for Space Construction

END EFFECTOR TYPE/FEATURES	APPLICATION AREAS		
	STRUT	UNION	MISSION EQUIPMENT
PARALLEL JAW HAND	ADAPTABLE	ADAPTABLE	ADAPTABLE
TWO-FINGER CLAW	ADAPTABLE	ADAPTABLE	ADAPTABLE
THREE-FINGER CLAW	QUESTIONABLE	ADAPTABLE	ADAPTABLE
FOUR-FINGER CLAW	QUESTIONABLE	ADAPTABLE	ADAPTABLE/SUITABLE
MECHANICAL HAND	COMPLEX	COMPLEX	COMPLEX
PROSTHETIC HOOK	NOT WELL MATCHED	POSSIBLE	POSSIBLE
HOOK HAND	ADAPTABLE	POSSIBLE	POSSIBLE
THREE JAW CHUCK	INEFFICIENT	ADAPTABLE	ADAPTABLE
SPECIALIZED TOOL	POSSIBLE	POSSIBLE	POSSIBLE
PROBE/DROGUE	NOT SUITABLE	SUITABLE	SUITABLE
CAGE/PROBE	NOT SUITABLE	QUESTIONABLE	ADAPTABLE
MULTI-FORK/RING	NOT SUITABLE	QUESTIONABLE	POSSIBLE
BOLT/THREADED HOLE	NOT SUITABLE	NOT SUITABLE	NOT SUITABLE
BALL-LOCK PIN/HOLE	NOT SUITABLE	NOT SUITABLE	NOT SUITABLE

development of hardware has to be considered. For example, for the RMS end effector to perform all of the required intricate operations in a routine fashion will require the development of a special adapter and/or new end effector. Any complex automated series of operations tends to imply a higher degree of risk and lower operational reliability. These negative factors can be overcome by providing EVA activity to help in case of emergency and as the back-up system. If one is planning for EVA then it is conceivable that manual operations will be scheduled into the experiment. This planned EVA will help reduce the complexity and hence cost of the equipment end items. There is the additional factor involved with the intensive training and cost of the EVA astronaut in simulation and preparing him for these space operations. If he works in conjunction with the RMS he will affect the timing (parallel or serial operation with EVA astronaut and RMS) and his safety (collision and non-interference with RMS and EVA astronaut).

The mission timeline developed for this study considered that the majority of the work would be accomplished using the RMS as the primary operating equipment. Most planned EVA would be a repeat of the RMS activity to calibrate the relative effectiveness and work performance between the EVA astronaut and the RMS. The total times derived will be approximately identical for the fully automated and the EVA assisted scenario, although individual operations are performed differently.

Each segment of the mission was divided into discrete operational elements and a standardized time allocated to each operational element. Although these times are estimates, they were based on ground simulation test data conducted with the RMS simulator and EVA simulation (References 7.2-7.4).

Table 7-4 indicates the relative times for various RMS operation elements. These times are for the ball and socket joint and the center hinge designs discussed in Section 7.1.1. If the experiment has different type joints, these operation times should be valid. All moves by the end effector were average at 1.5 minutes. Since the RMS is lightly loaded, the RMS would be moving at its higher velocity. The distance moved would depend upon which operation in the test was being performed, the mean distance is taken to be about 20 feet. The time allowance will allow for a conservative estimate in building up the time lines.

The docking and attachment operations have been assigned times in excess of 2 minutes. The difficulty arises from trying to dock an object already grasped by the RMS to a second object.

The build-up of the time lines are shown in Table 7-5 for the eight major operational tasks.

Task (1) preparing the RMS for operation will require power up, release and check out of the RMS. The time allocated for the operation is 24 minutes. Task (2), the release and unpacking of experiment container, Figure 7-16, involves the RMS attaching an end adapter tool which is part of the experiment payload manifest. This end adapter is required to perform the majority of the operations by grasping different size objects and release mechanisms. It is possible that the standard RMS snare end effector could be used but it would

Table 7-4. Time for RMS Operations

OPERATIONAL ELEMENT	MINUTES
SELECT AUTO PROGRAM	0.25
SELECT MANUAL AUGMENTED MODE	0.25
SELECT OPERATOR COMMAND AUTO SEQUENCE MODE	1.00
SELECT END EFFECTOR REF COORD. SYSTEM	0.25
SELECT ORBITER REF COORD. SYSTEM	0.25
MOVE END EFFECTOR TO NEW POSITION	1.5
DOCK END EFFECTOR TO GRAPPLE FIXTURE	2.5
RELEASE GRAPPLE FIXTURE AND BACK AWAY	1.0
ROTATE END EFFECTOR	0.5
RELEASE LATCHES AND RESTRAINTS	0.25
EVA MOVEMENT ACROSS PAYLOAD BAY (AVERAGE)	1.00
MAKE ATTACHMENT OF MODULE TO NODE	2.00
RELEASE ATTACHMENT OF MODULE FROM NODE	5.00
MAKE ELECTRICAL CONNECTIONS	2.00
TEST HINGE LOCKED IN POSITION	1.00
ATTACHED STRUCTURAL BALL JOINTS TO ATTACHMENT FIXTURE AND TEST	2.5
LOCK JOINTS OF UNION AT APEX NODE	5.0

impose "work around" design details to accommodate the grapple fixture on several pieces of test equipment. The test objective is not to develop and space verify a special end effector. The end effector is only a means to an end in deploying the flight experiment structure and attaching it to the test fixture.

The RMS is used to rotate, fully extend and lock the test fixture, unlatch and raise the container lid. These two operations will require the RMS to move in a constrained path. One end of the object pivots about a point while the RMS must transcribe an arc about this pivot point. This constrained motion in an arc could preload the RMS arm. If this preload is not removed prior to release of the RMS end effector, there will be a dynamic disturbance (twang) upon release. The stowed shaker module is temporarily moved to one side to allow opening of the container lid. The release of the latches holding down the various pieces of equipment has been accomplished using remotely operated latches.

Task 2 is estimated to be accomplished in apprxoimately 30.5 minutes.

The release and deployment of the flight rated structural module is undertaken in Task 3. Initially the restraining clamps are released and the bundle of struts is removed from their container and attached to the starboard side attachment fitting. The RMS will back away and move to the other end of the bundle of struts where the end effector releases a latch fitting restraining the module unions. Stored energy in the strut module will deploy the released end of the module while the RMS gradually backs away. The deployment rate of the strut module is controlled by the viscous dampers at each center hinge,

Table 7-5. Time Estimates for Eight Operational Tasks in Mission Scenario

	DESCRIPTION OF OPERATION	TIME (MINUTES)
1.	PREPARING RMS FOR OPERATION	
1.1	PREPARE GPC's FOR RMS OPERATION	3.5
1.2	MANEUVER TO DEPLOYMENT ATTITUDE	6.5
1.3	POWER UP MANIPULATOR ARM HEATERS	(6.5)
1.4	POWER UP, CHECK OUT CCTV/LIGHTS	(5.0)
1.5	POWER UP MANIPULATOR—UNLOCK HAND CONTROLLERS	(1.0)
1.6	STABILIZE—FREE DRIFT—RCS OFF	(1.0)
1.7	PERFORM MANIPULATOR ARM STATIC CHECKOUT	5.0
1.8	ROTATE MANIPULATOR ARM—RELEASE RESTRAINTS	2.0
1.9	SELECT AUTO PROGRAM—DEPLOY MANIPULATOR ARM	1.5
1.10	PERFORM MANIPULATOR FUNCTIONAL CHECKS	5.0
1.11	SELECT/VERIFY MANUAL AUG. CONTROL	0.25
	TOTAL TIME	23.75
2.	RELEASING AND UNPACKING OF EXPERIMENT CONTAINERS	
2.1	MOVE MANIPULATOR TO STOWED END ADAPTER POSITION	1.50
2.2	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
2.3	DOCK END EFFECTOR TO END ADAPTER AND COMPLETE GRAPPLE	2.50
2.4	RELEASE END ADAPTER TIE-DOWN RESTRAINTS	0.25
2.5	REMOVE END ADAPTER FROM STOWAGE CONTAINER	0.50
2.6	SELECT COMMAND AUTO MODE ORBITER COORD. SYSTEM	0.25
2.7	MOVE END EFFECTOR TO APEX OF STOWED TEST FIXTURE	1.50
2.8	SELECT END EFFECTOR REF. COORD. SYSTEM AND MANUAL AUG. MODE	0.25
2.9	DOCK END EFFECTOR TO APEX OF TEST FIXTURE AND COMPLETE GRAPPLE OPERATION	2.50
2.10	RELEASE LATCHES SECURING TEST FIXTURE TO STRUT CONTAINER BOX	1.25
2.11	SELECT C/A MODE AND ORBITER COORD. SYSTEM	0.25
2.12	ROTATE TEXT FIXTURE TO FULLY EXTENDED POSITION	1.00
2.13	ACTIVATE LOCKS TO SECURE FIXTURE IN EXTENDED POSITION	0.25
2.14	RELEASE GRAPPLE AT APEX OF TEST FIXTURE AND BACK AWAY FROM APEX	1.00
2.15	SELECT MANUAL AUGMENTED MODE AND MOVE END EFFECTOR TO POSITION IN FRONT OF SHAKER MODULE	1.50
2.16	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
2.17	DOCK END EFFECTOR TO GRAPPLE FIXTURE OR SHAKER MODULE	2.5
2.18	RELEASE ATTACH. LATCHES RESTRAINING SHAKER MODULE	1.25
2.19	BACK AWAY FROM CONTAINER BOX	0.50
2.20	SELECT O/C MODE—ORBITER COORDINATES	0.25
2.21	MOVE SHAKER MODULE TO PORT SIDE OF CARGO BAY	1.50
2.22	SELECT M/A MODE AND END EFFECTOR COORD. SYSTEM	0.25
2.23	DOCK SHAKER MODULE WITH TEMPORARY HOLDING FIXTURE	2.50
2.24	SECURE BERTHING LATCHES TO HOLD SHAKER MODULE	1.00
2.25	RELEASE GRAPPLE FIXTURE ON SHAKER MODULE AND BACK AWAY	1.00
2.26	MOVE END EFFECTOR TO TOP LID OF STRUT CONTAINER BOX	1.50
2.27	DOCK END EFFECT. WITH ATTACH. POINT ON LID AND GRAPPLE	2.50
2.28	RELEASE CONTAINER LID HOLD-DOWN LATCHES	0.25
2.29	MOVE END EFFECTOR TO OPEN CONTAINER LID	1.50
	TOTAL TIME	30.50

Table 7-5. Time Estimates for Eight Operational Tasks in Mission Scenario (Cont.)

	DESCRIPTION OF OPERATION	TIME (MINUTES)
3.	RELEASE AND DEPLOYMENT OF STRUCTURAL ELEMENTS	
3.1	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.2	M/A MODE MOVE END EFFECTOR TO STOWED STRUTS	1.50
3.3	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.4	DOCK END EFFECTOR TO GRAPPLE FIXTURE ON STOWED STRUTS	2.50
3.5	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.6	RELEASE LATCHES AND RESTRAINING CLAMPS AROUND STRUTS	0.25
3.7	WITHDRAW STRUTS FROM INSIDE OF CONTAINER BOX	1.50
3.8	MOVE STRUTS TO STARBOARD SIDE OF CARGO BAY	1.50
3.9	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.10	ROTATE STRUTS TO VERTICAL POSITION	0.50
3.11	DOCK STRUTS WITH STARBOARD HOLDING FIXTURE AND LOCK	2.50
3.12	RELEASE GRAPPLE FIXTURE AND BACK AWAY	1.00
3.13	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.14	MOVE END EFFECTOR TO OTHER END OF STRUT PACKAGE	1.50
3.15	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.16	DOCK TO GRAPPLE FITTING USED FOR RESTRAINING END UNIONS	2.50
3.17	RELEASE UNION RESTRAINTS AND BACK AWAY RMS	1.00
3.18	ALLOW STRUTS TO DEPLOY AND CENTER HINGES TO LOCK	2.00
3.19	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.20	MOVE TO CENTER HINGE NO. 1	1.50
3.21	ASSURE HINGE NO. 1 IS LOCKED	1.00
3.22	MOVE TO CENTER HINGE NO. 2 & ASSURE HINGE LOCKED	2.50
3.23	MOVE TO CENTER HINGE NO. 3 & ASSURE HINGE LOCKED	2.50
3.24	MOVE TO STRUT NODE NO. 1 ON EXTENDED STRUT BASE	1.50
3.25	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.26	DOCK WITH GRAPPLE ATTACHMENT AT NODE NO. 1	2.50
3.27	RELEASE LATCHES SECURING STRUTS TO STARBOARD ATTACH. FIXT.	0.25
3.28	LIFT STRUTS AWAY FROM FIXTURE	1.50
3.29	ROTATE END EFFECTOR WRIST 180° TO TURN STRUCTURAL MODULE RIGHT SIDE UP	0.50
3.30	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.31	MOVE NODE 1 TOWARD STARBOARD ATTACHMENT FIXTURE 1	1.50
3.32	SELECT END EFFECTOR COORD. SYSTEM	0.25
3.33	DOCK NODE 1 WITH ATTACH. FIXT. 1 & SECURE STRUCT. MODULE	2.50
3.34	RELEASE GRAPPLE FIXTURE AND BACK AWAY	1.00
3.35	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.35	MOVE RMS END EFFECTOR TO STRUCTURAL NODE NO. 2	1.50
3.36	SELECT END EFFECTOR COORD. REF. SYSTEM	0.25
3.37	DOCK WITH NODE NO. 2	2.50
3.38	MOVE NODE 2 INTO ATTACH. FIXT. 2 & SECURE STRUCT. MODULE	2.50
3.39	RELEASE GRAPPLE FIXTURE AND BACK AWAY	1.00
3.40	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.41	MOVE END EFFECTOR TO TOP OF STRUCTURE MODULE	1.50
3.42	SELECT END EFFECTOR COORD. REF. SYSTEM	0.25
3.43	DOCK AND GRAPPLE WITH TOP STRUCTURAL UNION	2.50
3.44	ROTATE AND DOCK NODE 3 INTO ATTACHMENT FIXTURE 3 AND SECURE STRUCTURE MODULE OFF-LOAD RMS ARM	5.00

Table 7-5. Time Estimates for Eight Operational Tasks in Mission Scenario (Cont.)

	DESCRIPTION OF OPERATION	TIME (MINUTES)
3.45	RELEASE UNION RESTRAINTS AT TOP OF STRUCTURAL MODULE AND BACK AWAY RMS	1.00
3.46	ALLOW STRUTS TO DEPLOY AND CENTER HINGE TO LOCK	2.00
3.47	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.48	MOVE TO CENTER HINGE 4 AND ASSURE HINGE IS LOCKED	2.50
3.49	MOVE TO CENTER HINGE 5 AND ASSURE HINGE IS LOCKED	2.50
3.50	MOVE TO CENTER HINGE 6 AND ASSURE HINGE IS LOCKED	2.50
3.51	MOVE TO APEX NODE OF STRUCTURAL MODULE	1.50
3.52	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.53	DOCK AND GRAPPLE APEX UNION	2.50
3.54	LOCK JOINTS OF UNION AT APEX NODE	5.00
3.55	RELEASE NODE AND BACK AWAY RMS	1.00
	TOTAL TIME	78.00
4.	**INSTALLATION AND ACTIVATION OF SHAKER MODULE**	
4.1	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.2	MOVE END EFF. TO SHAKER MODULE ATTACHED TO PORT SIDE OF CARGO BAY	1.50
4.3	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.4	DOCK AND GRAPPLE SHAKER MODULE	2.50
4.5	RELEASE MODULE/FIXTURE ATTACHMENT MECHANISM	0.25
4.6	BACK MODULE AWAY FROM HOLDING FIXTURE	1.00
4.7	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.8	MOVE SHAKER MODULE TO APEX NODE OF STRUCTURAL MODULE	1.50
4.9	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.10	DOCK SHAKER MODULE TO STRUCTURAL NODE	2.00
4.11	RELEASE MODULE AND BACK AWAY	1.00
4.12	MOVE AND CONNECT ELECTRICAL CONNECTION TO SHAKER MODULE	2.00
4.13	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.14	MOVE RMS TO STARBOARD ATTACHMENT FIXTURE	1.50
4.15	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.16	DOCK TO ELECTRICAL UMBILICAL	2.50
4.17	RELEASE UMBILICAL AND BACK AWAY	1.00
4.18	PERFORM ELECTRICAL AND SIGNAL CHECKS ON CONNECTIONS AND SHAKER MODULE	5.00
	TOTAL TIME	25.25
5.	**DYNAMIC EXPERIMENT AND MEASUREMENT**	
5.1	PREPARE EQUIPMENT AND RECORDING SENSORS	2.00
5.2	ACTIVATE SHAKER MODULE	1.00
5.3	CONDUCT FREQ. SWEEP TO EXCITE SERIES OF STRUCT. MODES	10.00
5.4	INCREASE ENERGY INPUT & PERFORM 2ND FREQ. SWEEP—REPEAT ENERGY INCREASE SEVERAL TIMES (MISSION PERMITTING)	30.00
5.5	PERFORM SINGLE-POINT RANDOM EXCITATION	5.00
5.6	REPEAT AT DIFFERENT ENERGY LEVELS	15.00

Table 7-5. Time Estimates for Eight Operational Tasks in Mission Scenario (Cont.)

	DESCRIPTION OF OPERATION	TIME (MINUTES)
5.7	SELECT RMS ORBITER COORD. REF. SYSTEM	0.25
5.8	MOVE RMS TO TOP OF SHAKER MODULE	1.50
5.9	SELECT END EFFECTOR COORD. REF. SYSTEM	0.25
5.10	DOCK AND GRAPPLE FOR SHAKER MODULE	2.50
5.11	RELEASE 3 LATCHES BETWEEN STRUT MODULE & TEST FIXTURE	0.25
5.12	SELECT ORBITER REF. COORD. SYSTEM	0.25
5.13	RAISE STRUT MODULE AWAY FROM CARGO BAY	1.50
5.14	ACTIVATE SHAKER MODULE	1.00
5.15	CONDUCT SERIES OF FREQ. SWEEPS AT DIFFERENT ENERGY LEVELS	30.00
5.16	CONDUCT SINGLE-POINT RANDOM EXCITATION AT DIFFERENT ENERGY LEVELS	15.00
	TOTAL TIME	115.50
6.	MODULE RELEASE, TRANSLATION, AND REDOCKING	
6.1	SELECT ORBITER REF. COORD. SYSTEM	0.25
6.2	MOVE END EFFECTOR TO STRUT NODE	1.50
6.3	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
6.4	DOCK WITH GRAPPLE FEATURE AT NODE	2.50
6.5	RELEASE LATCHES RESTRAINING STRUT MODULE TO TEST FIXTURE	0.50
6.6	SELECT ORBITER REF. COORD. SYSTEM	0.25
6.7	MOVE STRUT MODULE AWAY FROM ORBITER	1.50
6.8	PERFORM SEVERAL MANEUVERS AND ROTATIONS WITH STRUT MODULE	6.00
6.9	MOVE STRUT MODULE TO ATTACHMENT FIXTURE FOR BERTHING OP.	1.50
6.10	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
6.11	PERFORM BERTHING OP. REMOTELY WITH REAR ATTACH POINT IN TEST FIXTURE	2.50
6.12	RELEASE MODULE AND BACK AWAY	1.00
6.13	REPEAT ABOVE SEQ. OF OPERATIONS WITH ORBITER IN A CONTROLLED ATTITUDE MOVE WITH VERNIER RCS FIRING	18.00
6.14	REPEAT ABOVE SEQ. OF OPERATIONS AT DIFFERENT ORIENTATIONS	36.00
	TOTAL TIME	72.00
7.	EXPERIMENT BREAKDOWN AND RESTOWING	
7.1	SELECT ORBITER COORD. REF. SYSTEM	0.25
7.2	MOVE RMS END EFFECTOR TO SHAKER MODULE	1.50
7.3	DOCK AND GRAPPLE WITH ELECTRICAL CONNECTOR	2.50
7.4	DISCONNECT ELECTRICAL AND SIGNAL CONNECTOR	2.00
7.5	RELEASE CONNECT AND BACK AWAY	1.00
7.6	DOCK AND GRAPPLE WITH SHAKER MODULE	2.50
7.7	RELEASE ATTACHMENT OF MODULE FROM NODE	5.00
7.8	BACK SHAKER AWAY FROM STRUT MODULE	1.00
7.9	SELECT ORBITER REF. COORD. SYSTEM	0.25
7.10	MOVE SHAKER TO PORT SIDE TEMPORARY HOLDING FIXTURE	1.50
7.11	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.12	DOCK SHAKER TO TEMPORARY HOLDING FIXTURE	2.50
7.13	ACTIVATE HOLD-DOWN LATCHES TO SHAKER	0.25

Table 7-5. Time Estimates for Eight Operational Tasks in Mission Scenario (Cont.)

	DESCRIPTION OF OPERATION	TIME (MINUTES)
7.14	RELEASE RMS FROM SHAKER AND BACK AWAY	1.00
7.15	SELECT ORBITER REF. COORD. SYSTEM	0.25
7.16	DOCK WITH LANYARD MECHANISM	2.50
7.17	ACTIVATE MECHANISM TO REEL IN LANYARD AND RELEASE HINGE JOINTS & RETRACT TOP NODES OF STRUT MODULE	10.00
7.18	LOCK LANYARD MECHANISM	0.25
7.19	RELEASE RMS FROM LANYARD MECHANISM AND BACK AWAY	1.00
7.20	SELECT ORBITER REF. COORD. SYSTEM	0.25
7.21	MOVE TO RETRACTED APEX NODES	1.50
7.22	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.23	DOCK WITH SELECTED APEX NODE	2.50
7.24	LATCH AND SECURE ALL APEX NODES TOGETHER	5.00
7.25	UNLATCH THE 3 ATTACHMENTS OF STRUT MODULE TO TEST FIXTURE	0.25
7.26	SELECT ORBITER REF. COORD. SYSTEM	0.25
7.27	MOVE STRUT MODULE CLEAR OF TEST FIXTURE, ROTATE STRUT MODULE AND MOVE APEX TO STARBOARD ATTACHMENT FIXTURE	2.50
7.28	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.29	DOCK APEX NODE TO STARBOARD FIXTURE	2.50
7.30	RELEASE RMS FROM STRUT MODULE APEX AND BACK AWAY	1.00
7.31	MOVE RMS TO SECOND LANYARD MECHANISM	1.50
7.32	DOCK WITH LANYARD MECHANISM	2.50
7.33	ACTIVATE MECHANISM TO REEL IN LANYARD, RELEASE HINGE JOINTS, & RETRACT BOTTOM NODES OF STRUT MODULE	10.00
7.34	LOCK LANYARD MECHANISM	0.25
7.35	RELEASE RMS FROM LANYARD MECHANISM AND BACK AWAY	1.00
7.36	MOVE END EFFECTOR TO TOP LID OF STRUT CONTAINER, DOCK, RELEASE LATCHES, OPEN CONTAINER LID, AND SECURE	6.00
7.37	RELEASE RMS FROM CONTAINER LID	
7.38	MOVE TO STARBOARD FIXTURE, DOCK WITH STRUT MODULE RELEASE ATTACHMENT LATCHES & STOW MODULE IN STRUT CONTAINER	11.50
7.39	LATCH BUNDLED STRUT MODULE SAFELY INTO CONTAINER	2.00
7.40	MOVE RMS TO LID, DOCK AND RELEASE LID, CLOSE LID DOWN, AND ACTIVATE LATCHES	6.00
7.41	MOVE RMS TO SHAKER MODULE, DOCK, RELEASE, AND MOVE SHAKER ONTO CONTAINER LID, DOCK AND LATCH	12.50
7.42	MOVE RMS TO TEST FIXTURE, UNLOCK, REAR ARM TO UPRIGHT POSITION, AND RELATCH	8.25
7.43	STOW END ADAPTER, REMOVE FROM RMS	5.00
	TOTAL TIME	119.25
8.	RMS SHUTDOWN	
8.1	RELEASE PAYLOAD—RETRACT MANIP. ARM TO IC FOR AUTO	0.5
8.2	SELECT AUTO PROGRAM TO MOVE MANIP. ARM TO PRESTOW	0.25
8.3	MONITOR AUTO MANIP. ARM MOVEMENT TO PRESTOW	0.5
8.4	SELECT DIRECT MANIPULATOR ARM DR.	0.25
8.5	STOW MANIP. ARM IN RESTRAINTS, ROTATE TO STOWED POSITION	2.0
8.6	PERFORM POST-OPERATIONS MANIPULATOR STATUS CHECKS	5.0
8.7	SHUT DOWN MANIP. ARM HEATERS, LOCK HAND CONTROLS	0.5
8.8	POWER DOWN CCTV AND LIGHTS	0.5
	TOTAL TIME	9.5

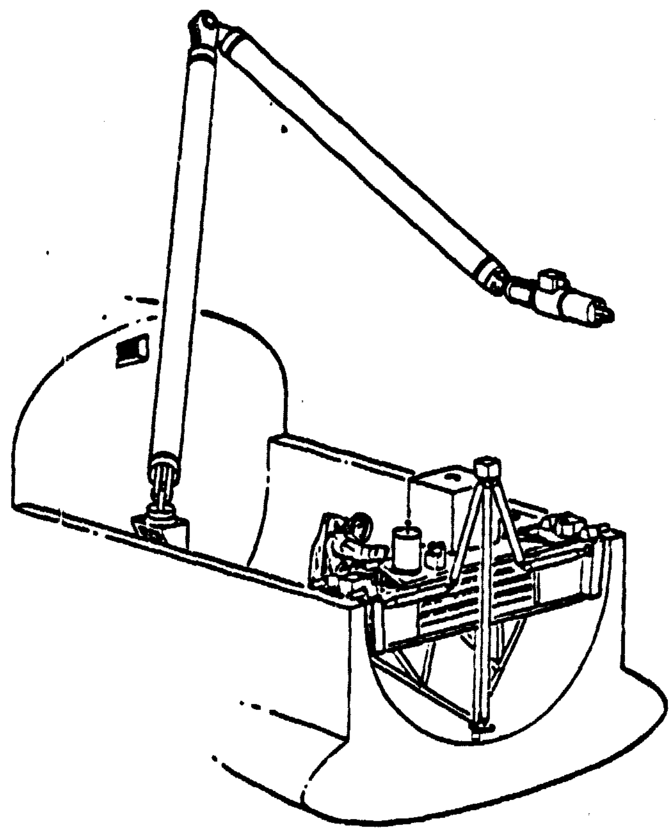


Figure 7-16. Releasing and Unpacking Equipment Containers

Figure 7-17. After the center hinges are fully deployed, the RMS is used to test whether these hinges are fully locked.

Next, the structure module is released from the starboard fitting, rotated through 180 degrees to turn the module right side up. Node 1 of the base structure module is mated to the fixed attachment fitting on the starboard side of the cargo bay, Figure 7-18.

The RMS is now concerned with testing the feasibility of making a multi-point attachment, Figure 7-19. Due to the dimensional uncertainty in the strut length due to tolerances arising from manufacturing, assembly, thermal, etc., the second attachment points might not be compatible. Therefore the attachment fitting on the port side will be linearly adjustable to allow for the mismatch in length. The argular displacement during the docking of Node 2 will be handled by "lead-in" wings on the attachment fitting.

The final attachment is made at the rear, Node 3. Due to the linear tolerance and motion at Node 2, the fitting at Node 3 must be able to float in all directions in a plane parallel to the base of the structure module.

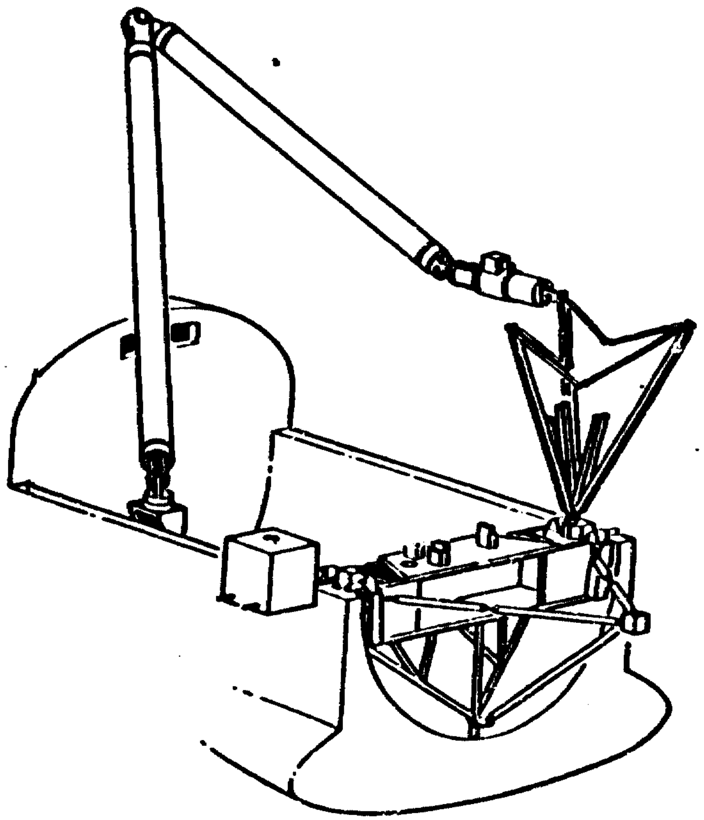


Figure 7-17. Release and First Partial Deployment of Structure Module

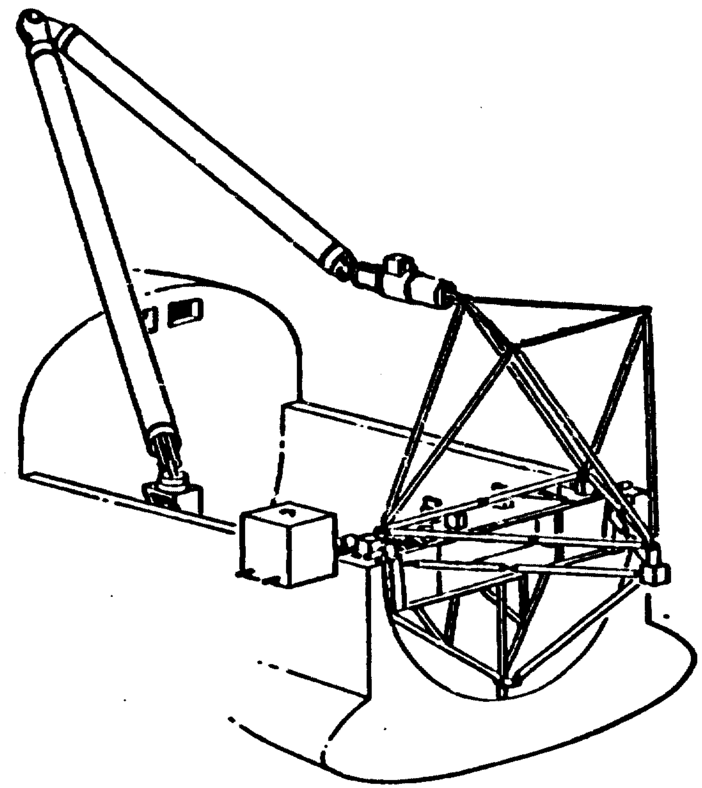


Figure 7-18. Structure Module Fully Deployed

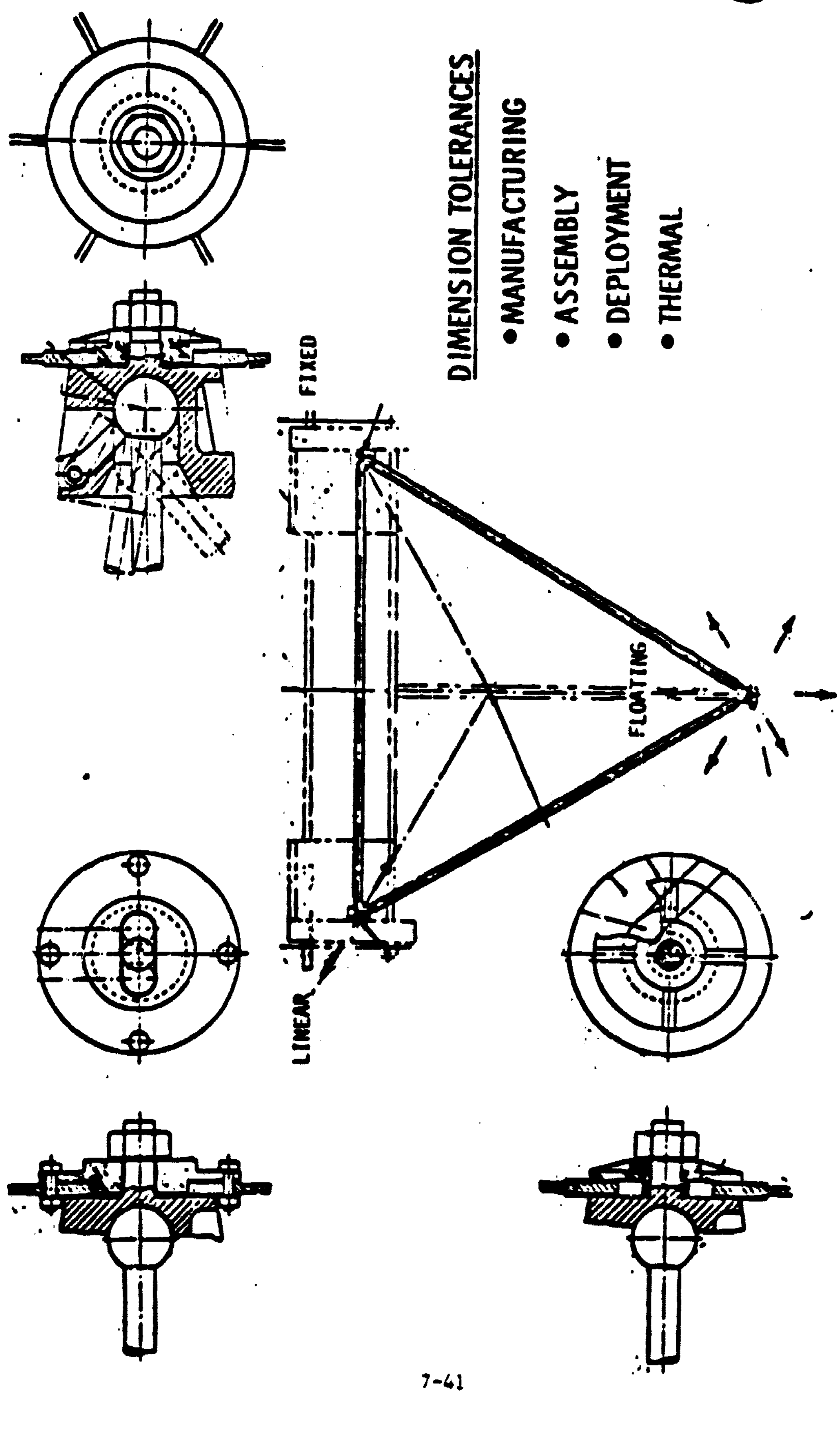


Figure 7-19. Multi-Point Attachment

After anchoring the base of the structure module, the RMS is required to release the restraining fitting on the unions on the apex and allow deployment of the rest of the structure module, Figure 7-18. When the structure module is fully deployed, the RMS is again used to check whether the center hinges are fully locked. The time for this task could amount to approximately 78 minutes.

In Task 4, the RMS must grasp the shaker module from its temporary position on the port side of the cargo bay and attach it to one of the structure modules apex nodes, Figure 7-20. The problem to be resolved is viewing the approach of the RMS with the shaker module attached to the node attachment fitting. The end effector may be several feet away from the strut node 4, and with the CCTV field of view partially blocked by the shaker module, rendezvous depth perception is the test objective under investigation. This type of operation simulates the attaching of subsystems/payloads, etc., to a major structure. For Experiment 2 there will be an astronaut in attendance to assist in the shaker module installation if difficulties should arise with the RMS installation (Figure 7-20). The shaker must be installed in order to vibrate the structure module for the structural dynamics part of the experiment. After successful installation the electrical connections are made and, power and signal checks to the shaker module are performed. Total time for shaker module installation and checkout has been estimated to be 25.25 minutes.

The second part of the flight experiment investigates the structural dynamic response of the structure module. One major objective is to obtain time varying deflection data of the structure module for varying modes of excitation. The structure module is initially vibrated when attached to the test fixture. Experiment is repeated at several levels of energy input and using the single point random excitation method.

The structure module is released from the test fixture and raised a couple of feet above the test fixture, Figure 7-21. The top of the shaker module is suspended from the RMS, and there are slack power and signal cables running from node 1 to the starboard attachment fitting. This attitude is an attempt to simulate a free-free suspension mode. The vibration tests are repeated in this mode suspended above the test fixture.

Total time for the dynamic experiment and data measurement is estimated to be about 115.5 minutes, including time for repeat cycles.

Task 6 is concerned with the orbiter and payload induced dynamics on one another. The RMS with the structure module attached performs several maneuvers trying to measure the effect of the light tip mass at a 50 ft distance on the stability of the orbiter, Figure 7-22. This effect will be negligible due to the light tip mass of the structure module. Next the RMS will berth the structure module to the test fixture. This operation will be repeated several times with the orbiter in different attitude modes. These modes will include free drift, attitude hold with vernier RCS thrusters firing and at various orientations. The attitude hold with thrusters firing will excite the RMS and its payload. The RMS motion must be allowed to damp out before successful structural berthing can be accomplished. The test objective is to determine how long is required for damping and what types of RMS operations can be undertaken depending on the attitude mode of the orbiter.

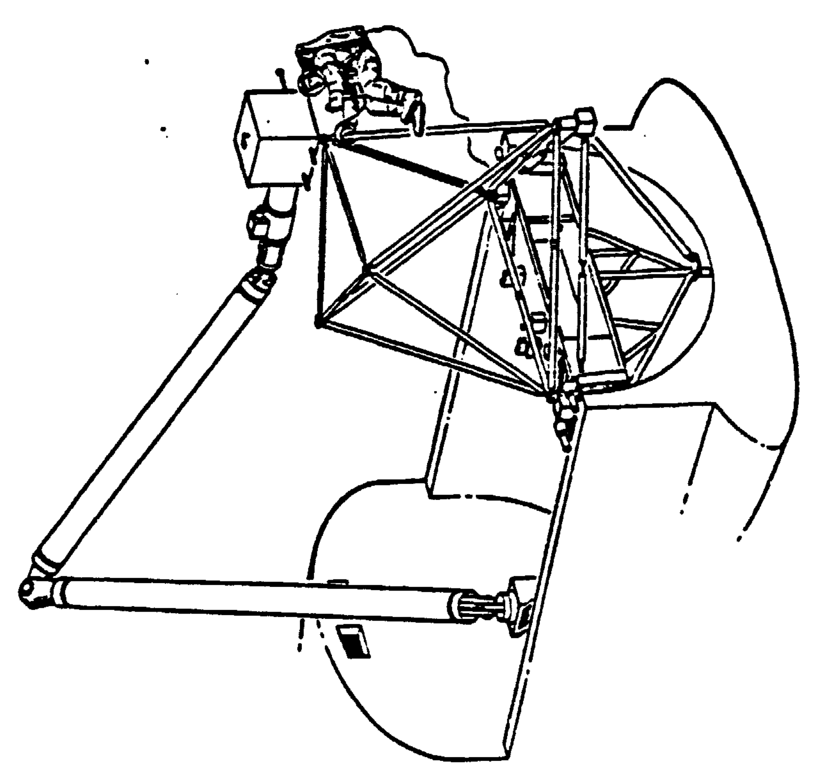


Figure 7-20. Astronaut Making Shaker Module Electrical Connection

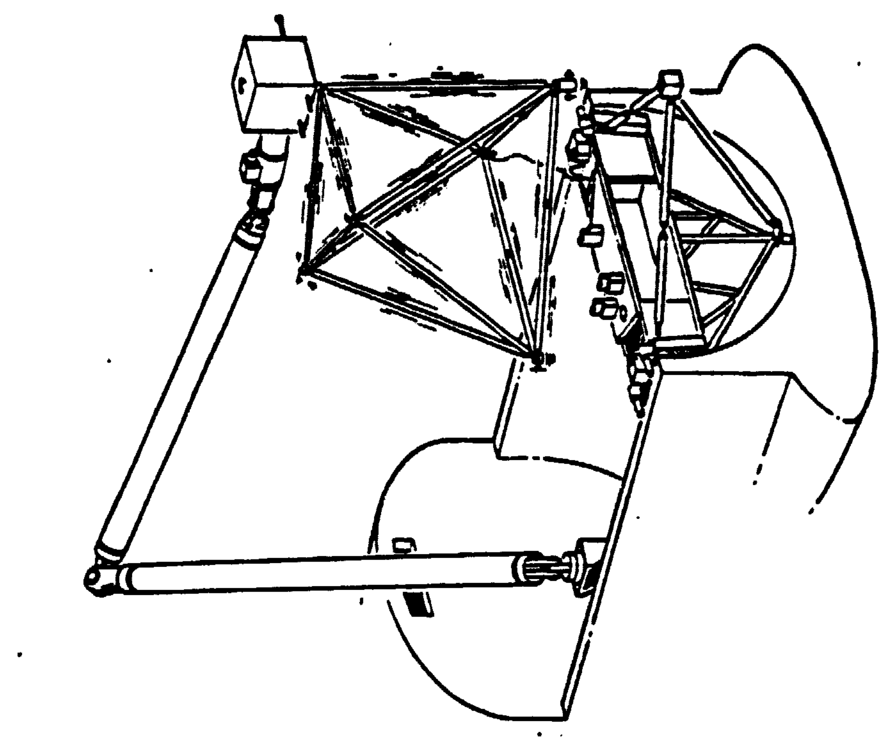


Figure 7-21. Structure Module Being Vibration Tested

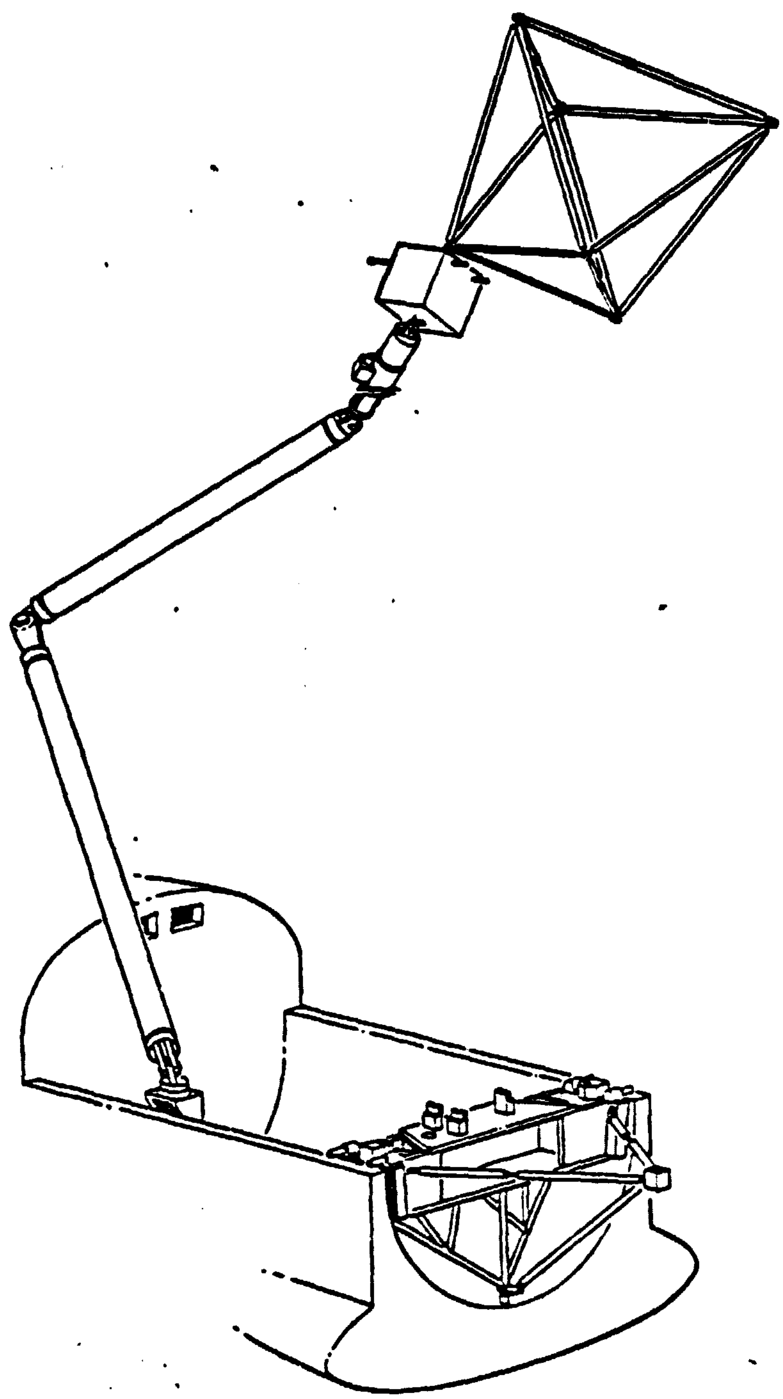


Figure 7-22. RMS Maneuvering Structure Module

After the dynamic portion of the experiment is completed, the RMS with astronaut assistance will remove and restow the shaker and structure module and the test fixture. The structure module requires the center hinges to be unlocked and restowed with the use of interconnected lanyards. Energy has to be put in the hinge system to restow the hinges and repackage the struts. The total time for the equipment breakdown and restowage is about 120 minutes. The final operation is the RMS shut down which takes less than 10 minutes.

A summary of the operational times shows in Table 7-6 that the total mission time will approach 8 hours including the repeat operations. It is felt that the operation times employed are extremely conservative, but the mission timeline as conceived does not include time allowances for contingencies and is 100% success orientated.

Table 7-6. Summary of Mission Timeline for Experiment 2

DESCRIPTION OF OPERATION	TIME (MINUTES)
1. PREPARING RMS FOR OPERATION	24.00
2. RELEASE AND UNPACKING OF EXPERIMENT CONTAINER	30.50
3. RELEASE AND DEPLOYMENT OF STRUT MODULE	78.00
4. INSTALLATION AND ACTIVATION OF SHAKER MODULE	25.25
5. DYNAMIC EXPERIMENT AND MEASUREMENTS	125.50
6. MODULE RELEASE, TRANSLATION AND REDOCKING	72.00
7. EXPERIMENT BREAKDOWN AND RESTOWING	119.25
8. RMS SHUTDOWN	9.50
TOTAL TIME	474

7.1.3 Dynamic Characteristics

The design concepts for any type of truss work large space structure (LSS) will result in low modal frequencies for the overall structure. Depending on where the LSS is required to operate, there will not be much separation between the control interaction, external disturbances, and the lowest natural frequency. This will be true for low earth orbit operation of large space structures, platforms that have high pointing requirements and low stiffness. Therefore, the control bandwidth may overlap structural frequencies. A design approach is to make the structure stiffer and increase the natural frequencies. With the multistrut/joint type of truss structure, either deployed or assembly in orbit, this may not be practical from either the packaging or weight standpoint.

Control theory with bandwidth separation or controlled lower frequencies tacitly assumes that structural modes above the controlled bandwidth will roll off with their inherent passive structural damping characteristics. This may not be true with this class of large highly flexible truss structure which has a very large population of joints. There have been studies by Honeywell that have shown that if there is only structural damping it is possible to have unacceptable amplification of uncontrolled modes appearing at the higher frequencies instead of the anticipated roll-off. This complicates the structural modeling. Damping mechanism must be modeled in the higher modes to faithfully represent the true behavior.

Therefore, from the control technology aspect it is important to understand the damping mechanism of the individual elements and hence the overall structure. The mechanism for the energy dissipation will depend upon the detail design and how it behaves in the space environment.

With the open-area long lightweight struts it is important to determine the contribution of structural damping from the struts and the viscous damping from the joints, and their respective deadbands and nonlinearity, whether the damping comes from flexing or friction rubbing between moving surfaces.

Therefore, this experiment will help assess where the damping occurs, its magnitude, and its characteristics. Armed with this knowledge, better attention can be given to design of elements contributing to structural damping and better prediction techniques for large complete structural models.

Analysis of conventional structures allowed for the updating of initially assumed values for the damping behavior by including pseudomodal damping data into the analysis. This modal damping data was obtained and updated from ground qualification tests and modal survey tests. It is possible the LSS in the future will not be completely ground-tested full-size and that the hard vacuum/zero-gravity effects have a noticeable effect on the dynamic behavior of these structures.

It is recognized that Experiment No. 2 has only 12 struts and six nodes plus six center hinges, but this simple structure will allow the easy

determination of individual damping characteristics by the separation of its lower modal frequencies. Once the damping of the microstructure is verified, then there will be better understanding of the damping of the macrostructure and the whole structure. Additional larger scale testing will be advisable where the population of nodes (joints/struts) is significantly increased.

The proposed structure for Experiment No. 2 was analyzed in detail to determine its dynamic characteristics. A finite element model, Figure 7-23, was created which is structural representative of the structure shown on Figure 7-3.

The model shown in Figure 7-23 has the following significant characteristics:

- A vertical post (Bar 100) that is 0.50 meter (20 in.) high with a uniformly distributed total mass of 91 kg
- Provision of the short elements at the member-to-member joints (Examples 2-25 and 5-29) to represent the joint damping and stiffness
- Provision of short elements at the center of the foldable truss elements (Examples 11-12 and 13-14) to represent the stiffness and damping characteristics of the center folding/locking joints
- All the elements have a cross sectional area of 4.84 cm^2 (0.75 $in.^2$) and moments of inertia of 35.4 cm^4 (0.85 $in.^4$).

The sinusoidal loading imposed on Node 7 was a load moment $My = 113 \sin 2\pi f t$ NM, with f = 100 Hz. Figure 7-24 shows the bending moment experienced at the short Bar 1 closest to the excitation input and Bar 32 which is furthest away at the base of the structure. Two different damping coefficients were used for the joints (short bars) to demonstrate the variation in structural response. The deflection responses are shown in Figure 7-25 for the X-direction and Figure 7-25 for the Z-direction.

The modal values obtained from the NASTRAN modal analysis are:

17.8 Hz - first
18.4 Hz - second
31.1 Hz - third
32.2 Hz - fourth
33.6 Hz - fifth
36.5 Hz - sixth

Displacement and phase data are shown across one hinge joint that has built-in damping. Data at Node 11 (Figure 7-26) and Node 12 (Figure 7-27) are for two values of damping coefficients. Both figures show that for low damping (0.05) that there are two distinct frequency regions (18 Hz and 80 Hz) where there are significant vibration amplitudes. The higher damping coefficient (0.5) will reduce the first mode response but reduces the higher frequency responses even more.

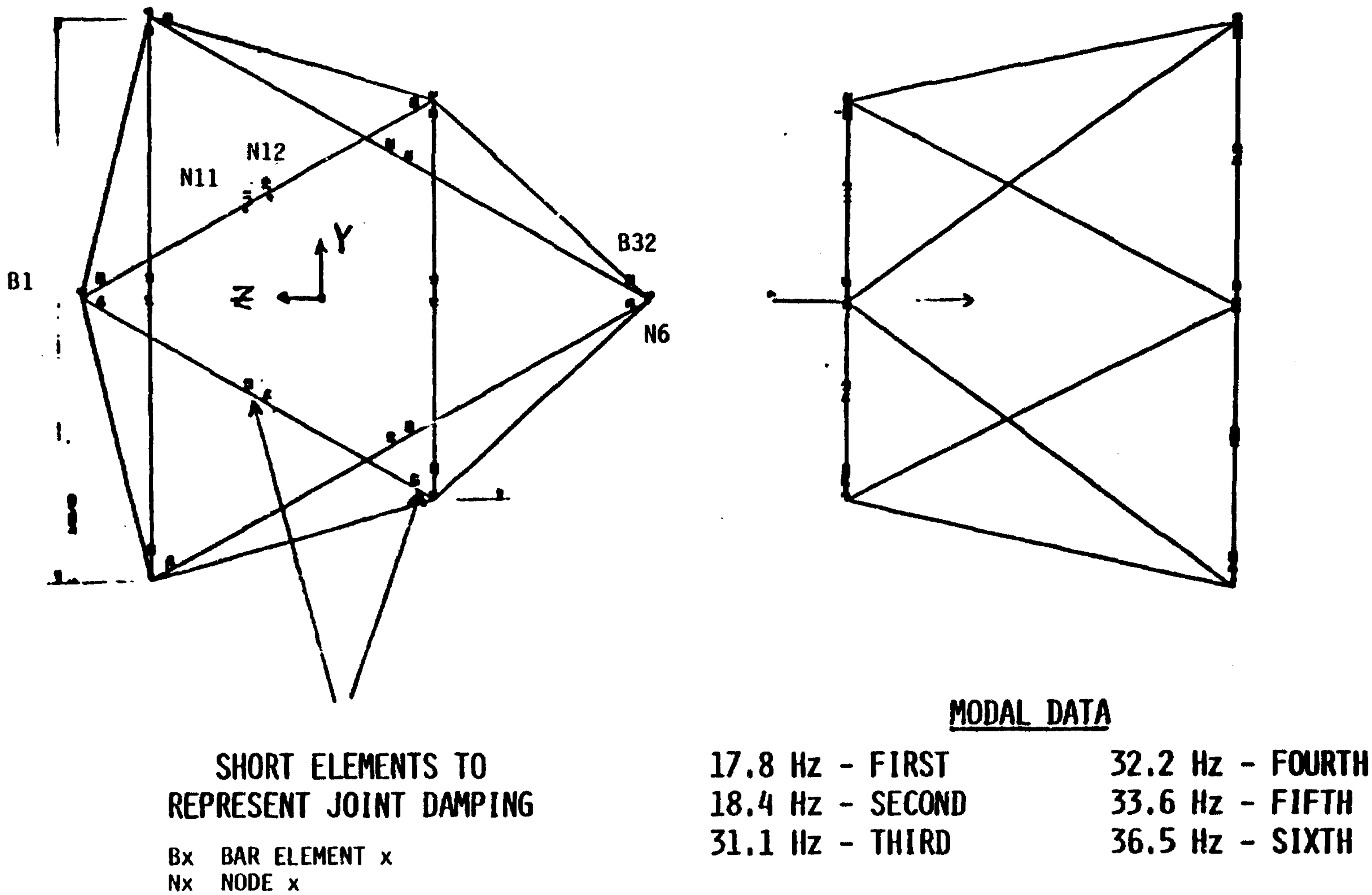


Figure 7-23. Finite Element Model of Structure Module

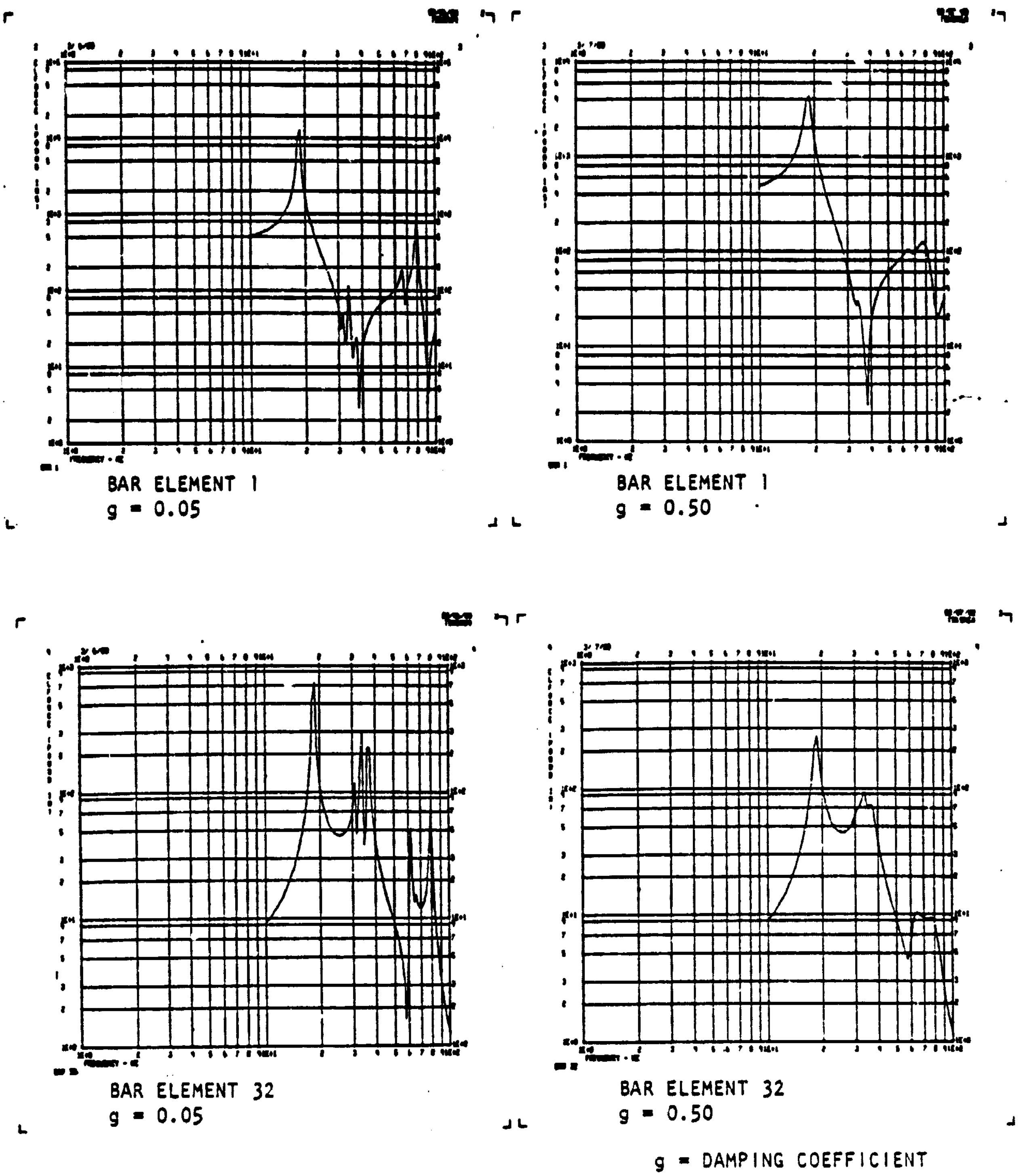
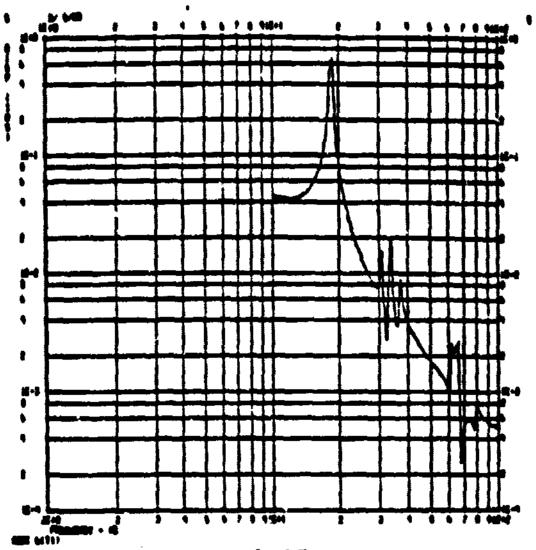
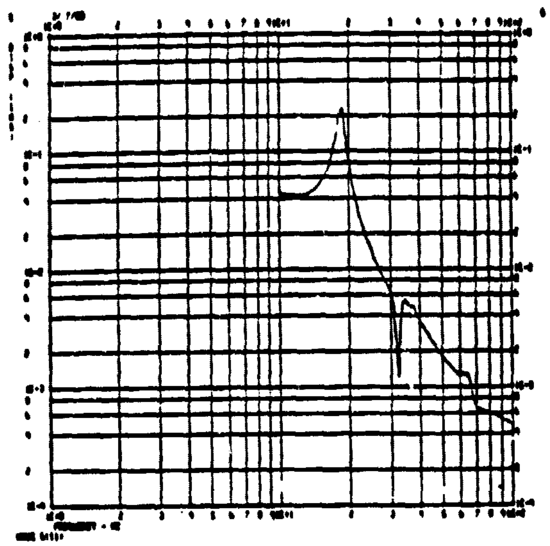


Figure 7-24. Bending Moments (lb-in.) in Bar Elements

X - DISPLACEMENT

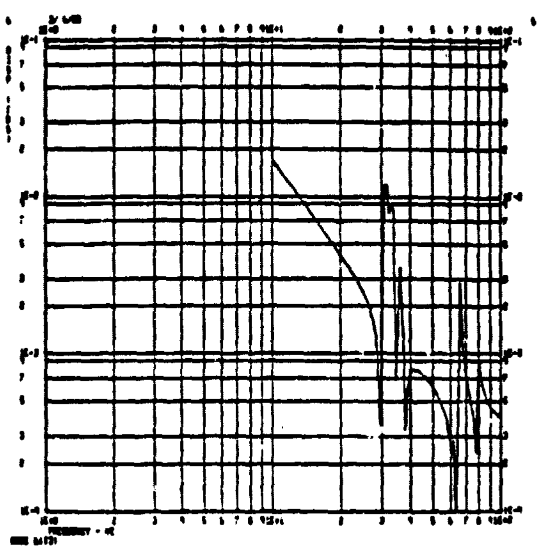


g = 0.05

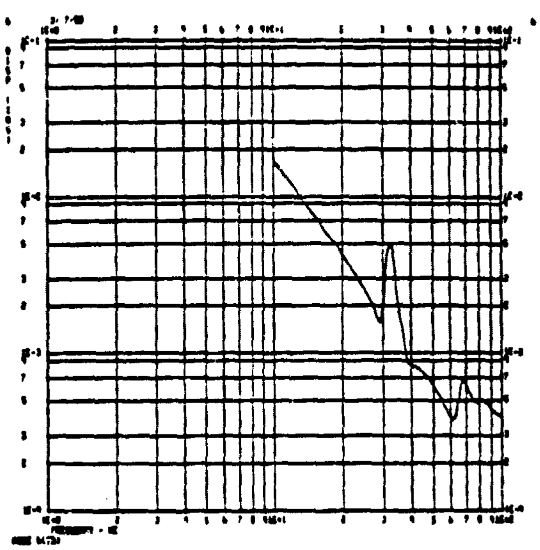


g = 0.50

Z - DISPLACEMENT



g = 0.05

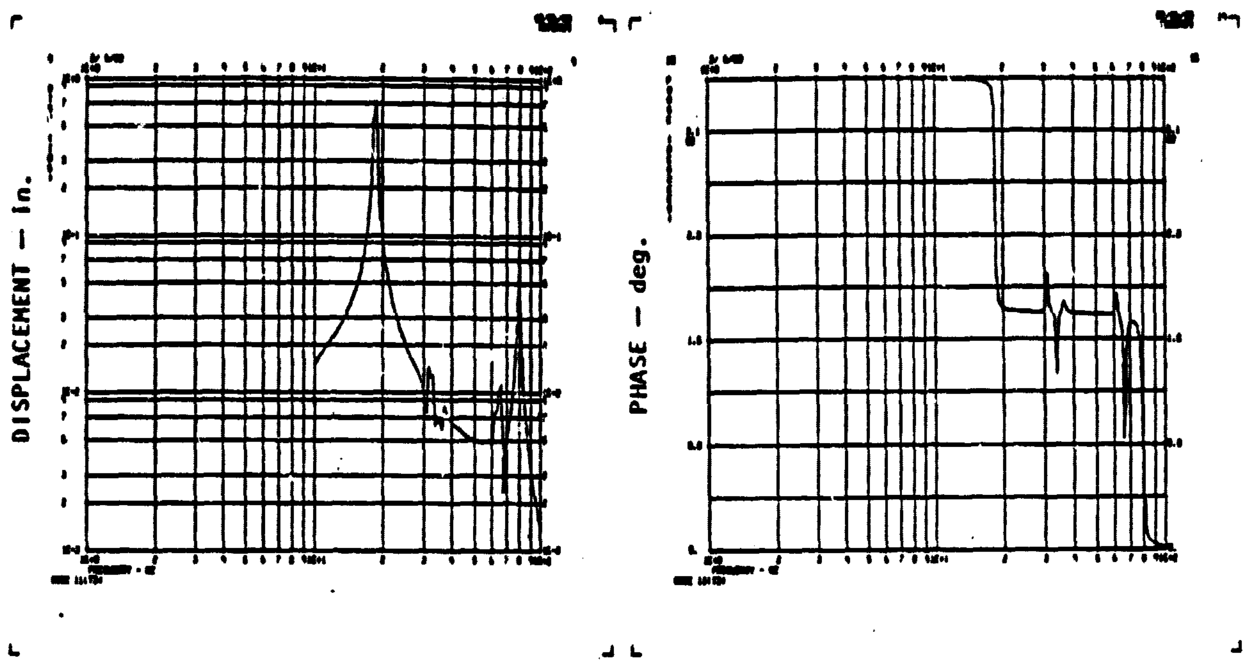


g = 0.50

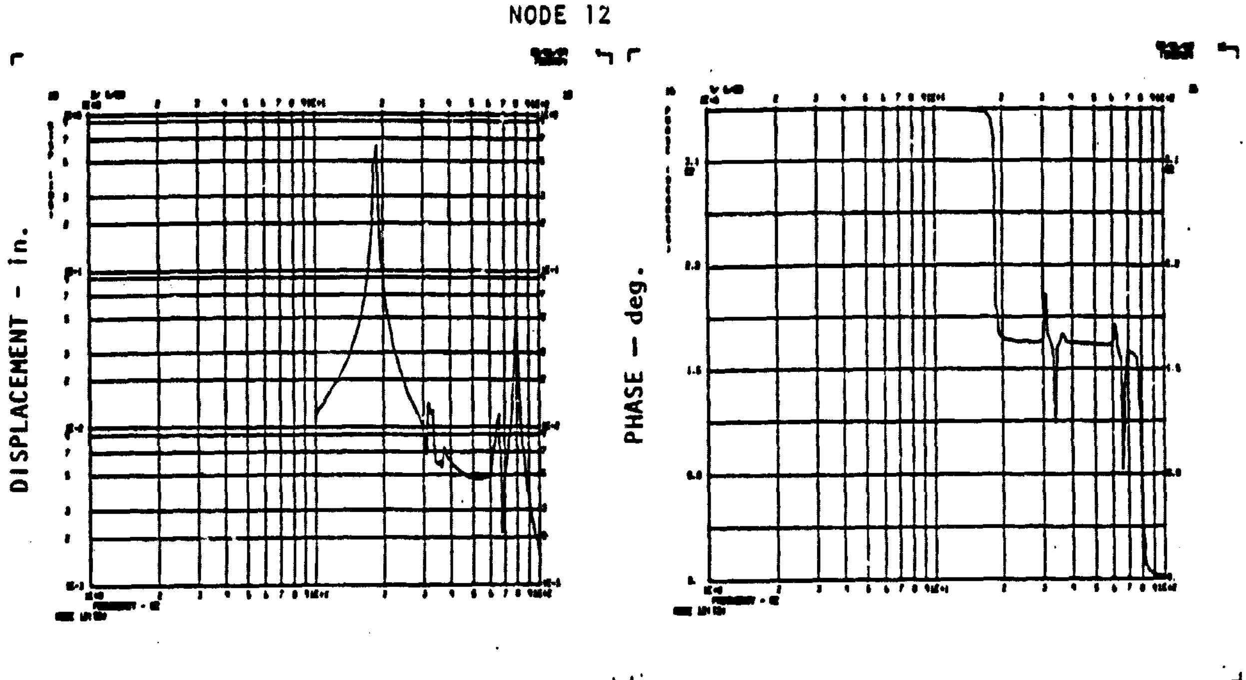
g = DAMPING COEFFICIENT

Figure 7-25. Displacement at Node 6 — (in.)

NODE 11



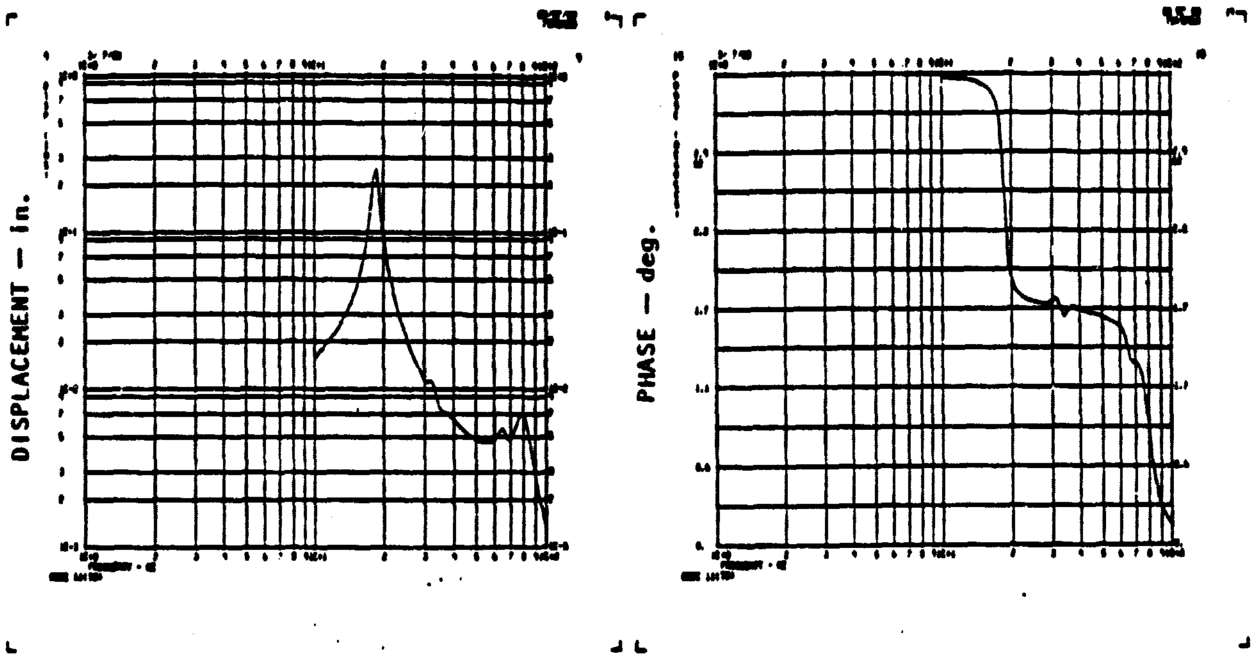
NODE 12



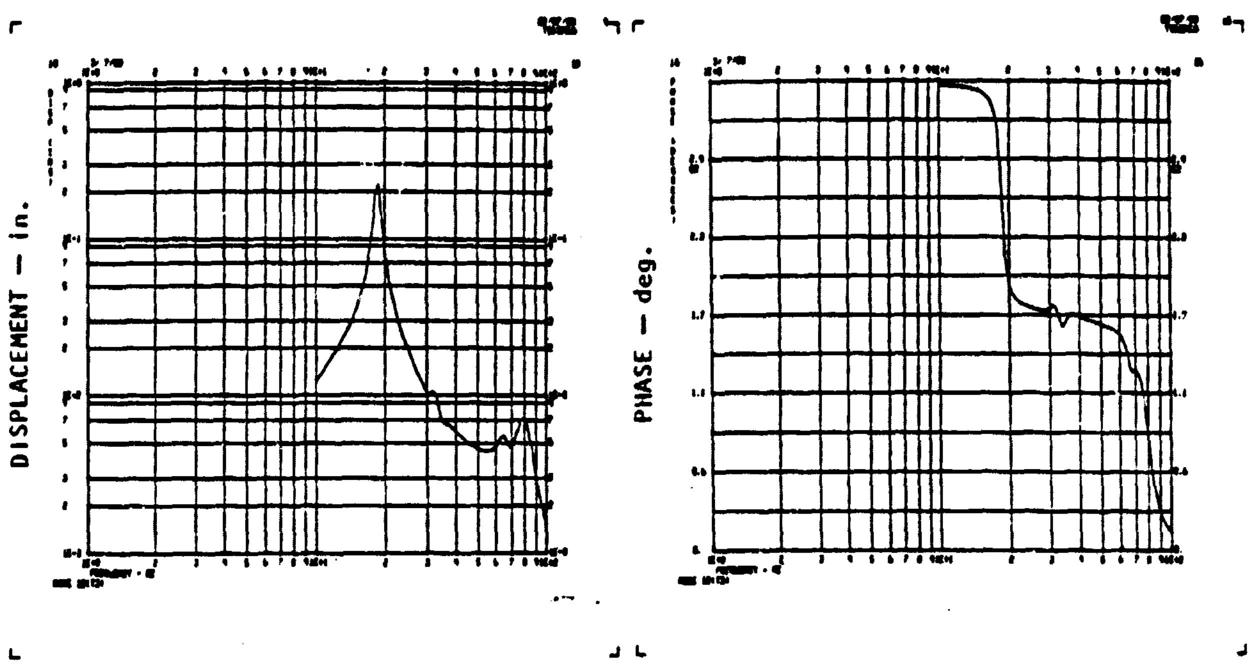
g = DAMPING COEFFICIENT

Figure 7-26. Damping Across a Center Hinge — g = 0.05

NODE 11



NODE 12



g = DAMPING COEFFICIENT

Figure 7-27. Damping Across Center Hinge — g = 0.50

The space measurement of this information will be an important test itself that has direct application to control of large space structures. The modal frequency of this small deployable structure is still within the measurement capability of Piezo-electric accelerometers, but large low-frequency structures may not. Therefore, new methods of displacement measurements can be tested on board Experiment No. 2.

There are disturbances during the construction operation that could impact on the precision placement accuracy of the RMS and the mission "time-out" to allow for vibrational settling duration. Hence tasks in the experiment will be attempted with the orbiter in a free-drift mode and subsequently with the orbiter in a specific attitude hold.

The orbiter induced disturbances were considered first by considering the orbiter in various gravity-gradient modes, and later in an inertial-hold attitude. A completely free-drift attitude will allow perhaps the orientation of the direct illumination and background clutter to be such that construction operations and viewing of detail operations are impractical, if not impossible.

Data was obtained for the effects of aerodynamic and gravity-gradient disturbance torques on the attitude histories for three gravity-gradient modes. Example simulation data for the three GG modes are presented in Figures 7-28, 7-29, and 7-30. The data includes aerodynamic torques and is for an orbital altitude of 417 km (225 nmi). Worst-case initialization errors were utilized. These consist of an error in initial alignment of the principal axes of inertia of one degree (all axes), and initial attitude rate errors corresponding to one full minimum impulse bit from the vernier RCS thrusters (all axes). The rate errors due to the vernier RCS minimum impulse bit size (40 milliseconds) are 0.0014 deg/sec in roll, 0.00097 deg/sec in pitch, and 0.00071 deg/sec in yaw. To obtain worst-case conditions, the sign of these errors was adjusted so as to produce an attitude divergence in the same sense as produced by the aerodynamic torques. Hence the resulting drift time data will be pessimistically low.

The attitude time histories for the X-POP Z-LV mode (Figure 7-28) and Y-POP Z-LV mode (Figure 7-29) illustrate typical divergence of these unstable GG modes. In each case the most rapid divergence occurs about the axis perpendicular to the plane of the orbit.

Figure 7-30 illustrates the attitude time histories for the stable Z-POP X-LV GG mode. As expected, the pitch and yaw motion due to the disturbance sources are bounded sinusoids of small amplitude, and at the GG libration frequency. The roll motion is also bounded due to the favorable dynamic cross-coupling with the other axes, but has a much larger amplitude and lower frequency. The trend of the data indicates relatively steady-state response in the three orbits simulated, and would not appear to be diverging further. It is concluded that this mode provides very long drift times (many orbits) without thruster firings under the assumption that moderate roll attitude excursions are acceptable.

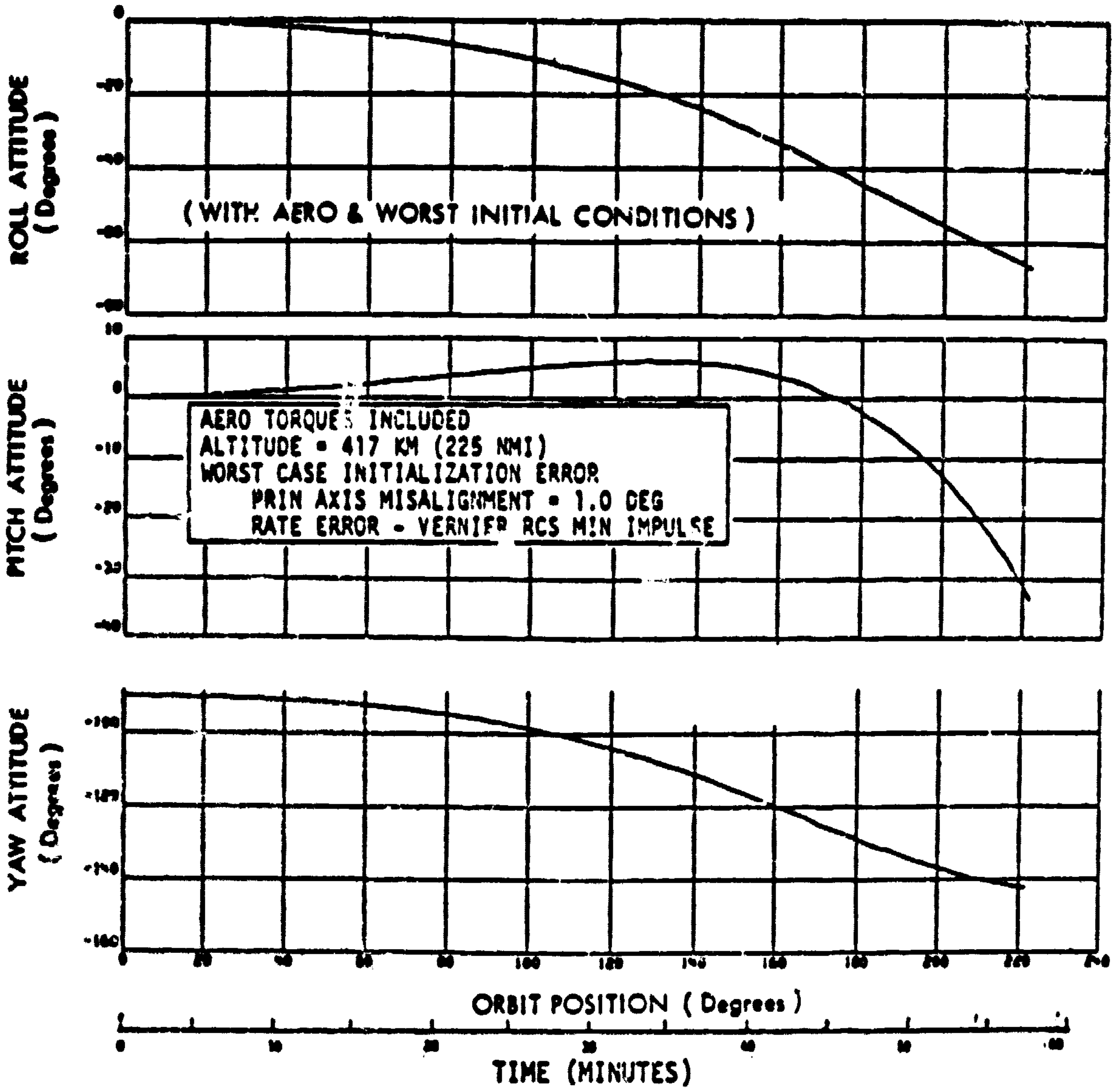


Figure 7-28. Attitude Histories for X-POP, Z-LV GG Mode

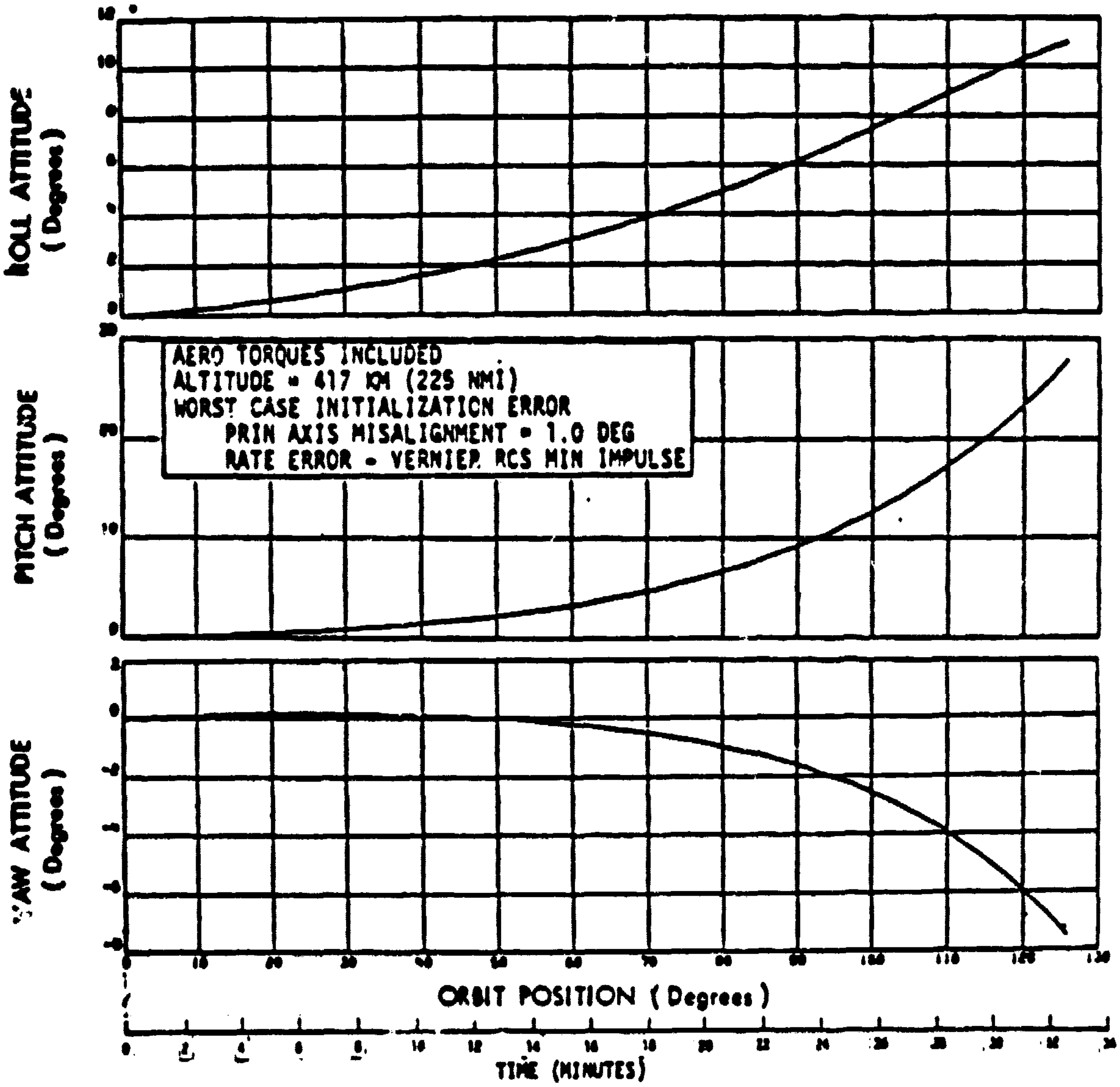


Figure 7-29. Attitude Histories for Y-POP, Z-LV GG Mode

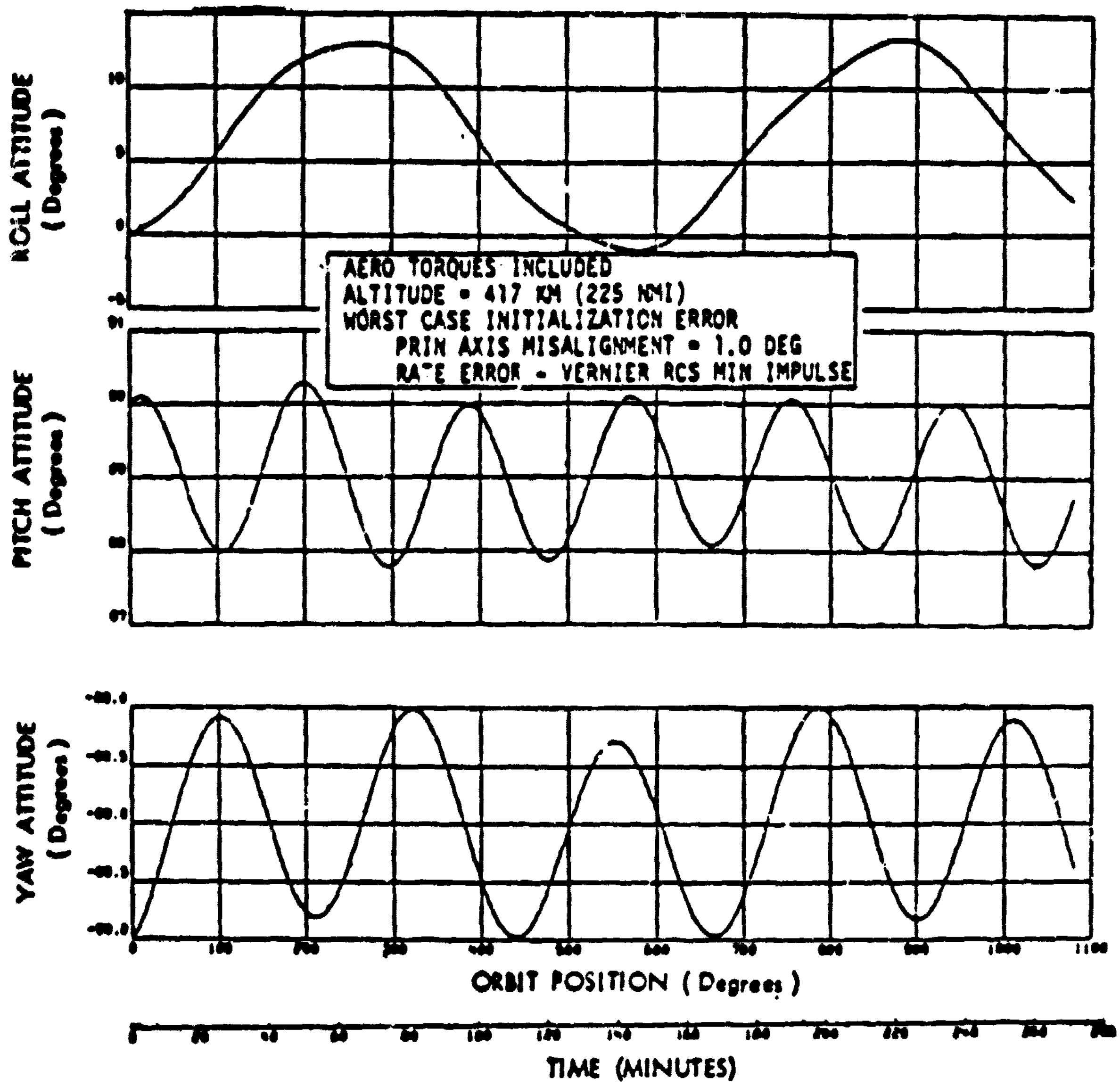


Figure 7-30. Attitude Histories for Z-POP, X-LV GG Mode

The effects of aerodynamic torques on drift time for the three GG modes are presented in Figures 7-31, 7-32, and 7-33.

The curves of Figure 7-31 illustrate that the X-POP Z-LV mode is sensitive to aerodynamic torques and substantial reductions in drift time begin to occur below an altitude of approximately 400 km (216 nmi). This is due to a relatively large roll aerodynamic torque acting on the axis of smallest moment of inertia. Reasonable drift times are available from this mode for high-altitude missions.

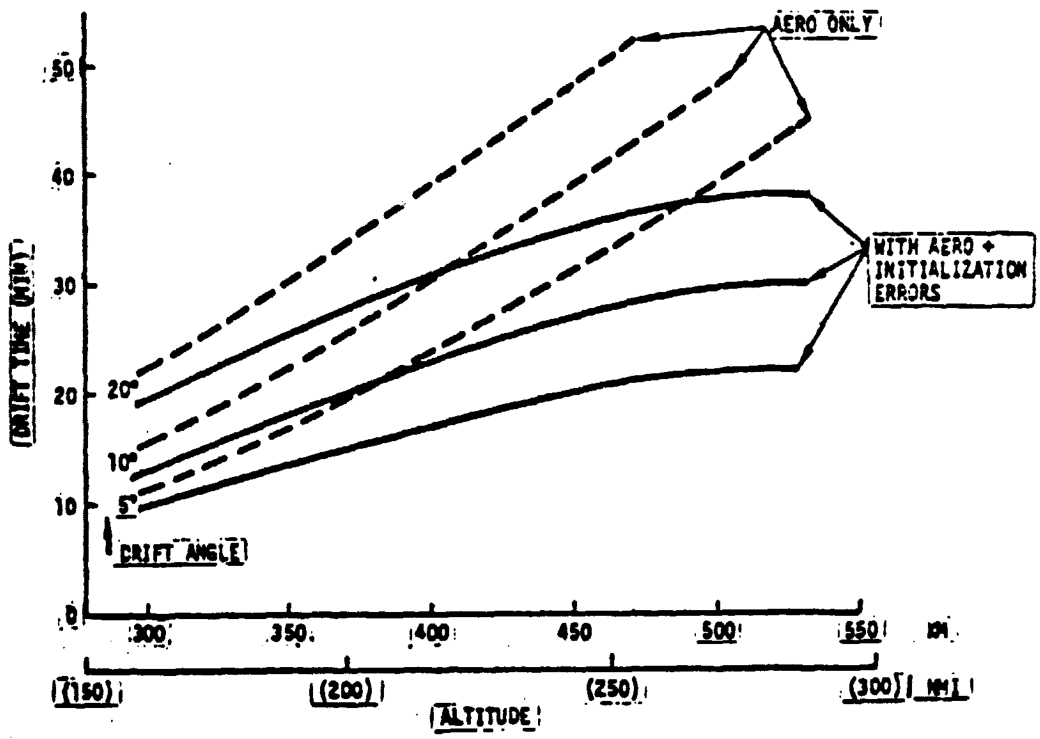


Figure 7-31. Effect of Aerodynamics on Drift Time (X-POP, Z-LV GG Mode)

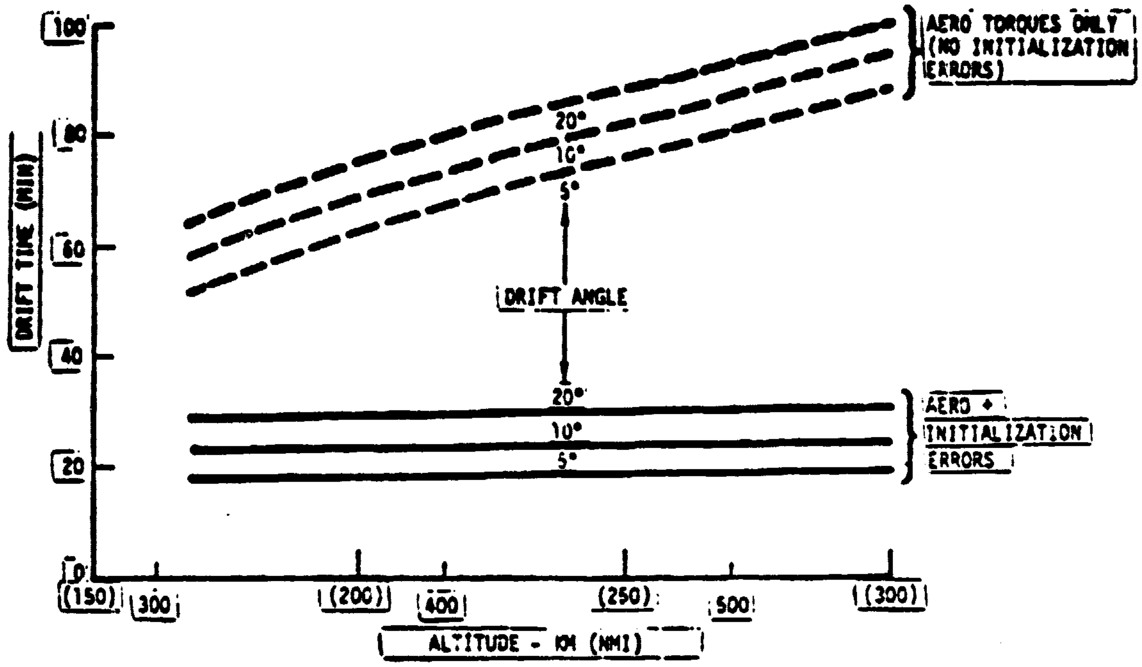


Figure 7-32. Effect of Aerodynamics on Drift Time (Y-POP, Z-LV GG Mode)

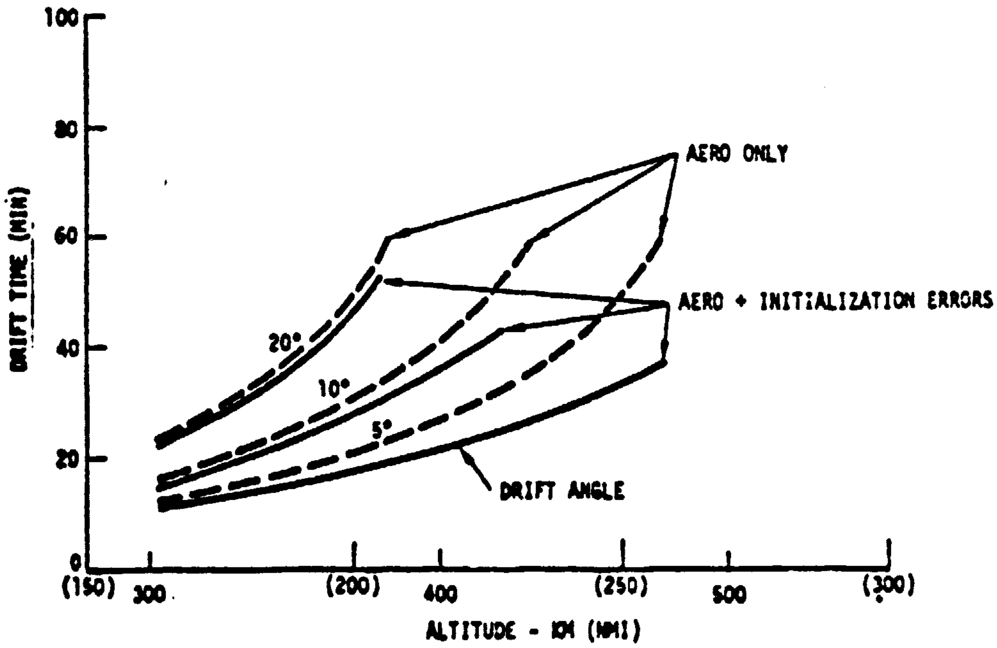


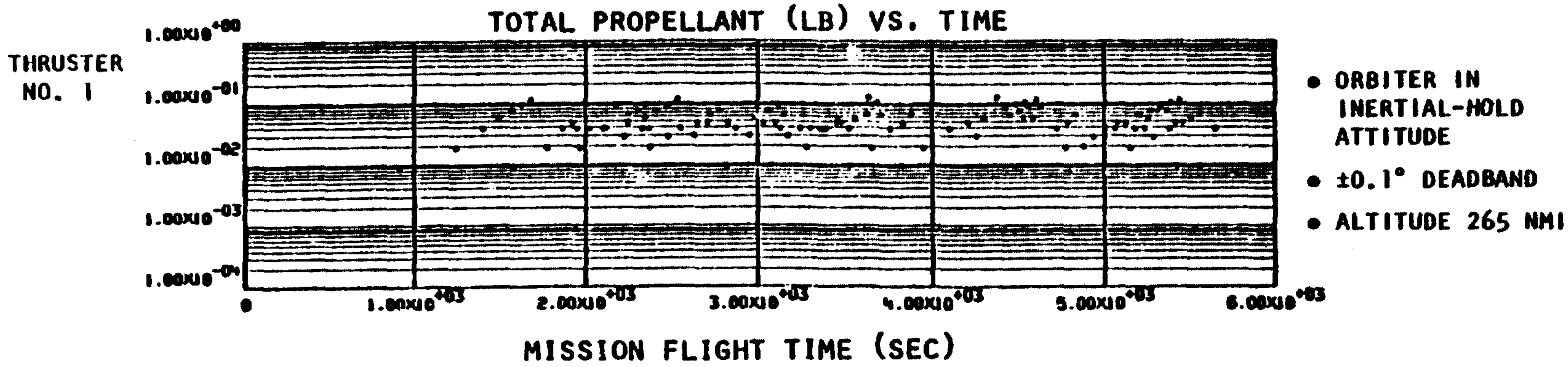
Figure 7-33. Effect of Aerodynamics on Drift Time (Z-POP, X-LV GG Mode)

The curves of Figure 7-32 illustrate that the Y-POP Z-LV mode (orbiter attitude) is relatively insensitive to aerodynamic torques. This is due to relatively small aerodynamic torques (pitch and yaw) acting in the axes of largest moments of inertia. The available drift time for this unstable GG mode is dominated by the attitude state initialization errors. This mode provides reasonable drift time for operation at much lower altitudes than the previous mode and can probably operate below 300 km (162 nmi).

The curves of Figure 7-33 illustrate that the Z-POP X-LV mode is somewhat sensitive to aerodynamic torques. However, it may be recalled (see Figure 7-30) that the drift motion for this mode is bounded, and if moderate drift angles in roll are tolerable, then the drift time becomes very large (many orbits) relative to the other modes. For altitudes greater than approximately 400 km (216 nmi) the maximum drift angle is less than 20 degrees, and decreases for increasing altitude.

These gravity-gradient modes would allow the construction operation to proceed without disturbances from the orbiter's vernier RCS thrusters. The only consideration will be whether viewing and background lighting allows for construction operations.

If we consider the orbiter in an attitude hold mode, then there will be periodic thruster firings which will vibrate both the RMS and the LSS, and require prescribed settling times before operations can proceed. With the orbiter at a 265 nmi attitude in a worst-condition inertial hold and a ±0.1-degree deadband, a typical thruster firing duty cycle together with propellant used is shown in Figure 7-34. The mean time between firings (MTBF) is about 50—70 secs per thruster. If we consider all thrusters, the MTBF will be about 10 secs. This could be considered as a continuous disturbance when compared to the settling times of the RMS and structure. If the deadband is opened up, then the MTBF will increase correspondingly. The results from Experiment No. 2 will verify what are acceptable flight modes and the percentage of time that construction operations can be undertaken with respect to the total mission time available.



THRUSTER FIRING STATISTICS

THRUSTER	PROP. (LB)	TOTAL FIRES	MPPF (LB)	MTBF (SEC)
1	5.656846	123.	0.045991	46.01
2	5.691877	119.	0.047831	47.55
3	4.973834	80.	0.062173	70.74
4	5.000103	80.	0.062501	70.74
5	7.127990	127.	0.056126	44.56
6	7.163014	123.	0.058236	46.01

Figure 7-34. Typical Vernier Thruster Firing During Attitude-Hold Mode

7.1.4 Experiment 2/Orbiter Interface

The orbiter support for and interfaces with the deployed structure dynamics experiment, Experiment 2, is discussed in two general areas. These are (1) the mechanical/installation interfaces with the orbiter payload bay and other orbiter systems and (2) the experiment interface with the orbiter systems and other STS supporting systems during the experiment on-orbit operations. These two interface areas are summarized in Table 7-7.

The experiment component and support equipment interfaces with the orbiter considered are primarily those structural, mechanical and electrical installations which are to be integrated with the orbiter flight vehicle prior to the mission launch. The currently proposed LSS experiments constitute only a partial load for the orbiter so the LSS experiment is therefore only a part of the orbiter/payload integration task to be performed by the payload integration activity. The following summaries provide a preliminary discussion of the requirements that the experiment designer and mission planer must consider in order to include Experiment 2 in one of the early shuttle orbiter flights. The nine generic experiment "component" items listed in Table 7-7 will be discussed individually in the following section. Automated experiment operations are assumed as basic with EVA backup. Supplementary tests using EVA operations may be scheduled.

Deployable Structure Module

The Experiment 2 deployable structure is a major component of the experiment. Experiment objectives include evaluating the feasibility of space operations for deploying a folded structure using the thin developed folded struts, multipurpose unions, and orbiter based automated and/or EVA operations. It also is desired to observe and measure the dynamic response of the structure to various vibration loads which may be imposed on a deployable type structure by mission operations (e.g., during platform orbit-to-orbit transfer). The structure therefore will require instrumentation installation and data recording interface arrangements. Thus electrical power, power control and data displays for the experiment operators in the AFD will be required.

The folded structure assembly will be packaged on an experiment container during launch-to-orbit and during the return-to-earth phase of the mission. The orbiter structural interface will then be with the "container" rather than directly with the experiment structure itself. The packaged structure must be retained within the container subject to the same level of structural load criteria that are specified for "payload" installations. The largest component of g-loading constraints would be the "abort landing" stress of 9-g in the X direction (Reference 7.5). The experiment packaging design will analyze the transfer of the experiment assembly loads through the container structure to the container attachment to the orbiter structure.

Experiment Container and Support

The experiment container is that structure designed to support the Experiment 2 structural cell and equipment during the orbiter translation to and from orbit. It also provides the basic connection between the orbiter

Table 7-7. Experiment No. 2 Orbiter Interface Matrix

EXPERIMENT COMPONENTS AND OPERATIONS	SELECTED ORBITER SYSTEMS AND SUBSYSTEMS			AVIONICS														
	PAYLOAD BAY STRUCTURE	PAYLOAD BAY PALLET/CONTAINER	ORBITER RMS	COMM. AND TRACKING	DISPLAYS AND CONTROLS	CAUTION AND WARNING	DATA PROC. & SOFTWARE	ELEC. POWER DIST. & CONTR.	ELECTRICAL POWER	PAYLOAD BAY LIGHTING	CLOSED-CIRCUIT TV (CCTV)	AFT FLIGHT DECK CONSOLE	AFT FLIGHT DECK CREW	EVA CREW	MANNED MAN-EUVERING UNIT	CHERRY PICKER	REACTION CONTR. SYSTEM (RCS)	P/L GROUND HANDLING SYS.
COMPONENTS																		
1. DEPLOYABLE STRUCTURE		X					X	X	X			X						
2. EXPERIMENT CONTAINER	X	X						X	X			X						X
3. CONTAINER SUPPORT	X	X			X	X						X						
4. EQUIPMENT MODULE	X	X			X	X	X	X	X	X		X						
5. UMBIL., WIRE HARNESS, ETC		X																
6. HAND. & POS. AID (HAPA)																		
7. RMS	X		-		X	X	X	X	X		X	X						
8. SPEC. END EFFECTOR (SEE)		X			X		X	X	X			X						
9. MANNED MANEUV. UNIT (MMU)	X	X													-			
10. CHERRY PICKER																-		
OPERATIONS																		
1. PREPARE RMS FOR OPERA.			X		X		X	X	X			X	X					
2. RELEASE & UNPACK EXPMT CONTAINERS		X	X		X	X	X	X	X			X	X	TBD				
3. RELEASE & DEPLOY STRUCTURAL ELEMENTS		X	X		X	X	X	X	X	X		X	X					
4. INSTALL & ACTIVATE SHAKER MODULE		X	X		X	X	X	X	X	X		X	X	X				
5. PERFORM DYNAMIC EXP OPS, RECORD MEASUREMENTS			X	X	X	X	X	X	X	X		X	X					
6. PERF. MOD. RELEASE, TRANSLATION & REDOCKING			X		X	X	X	X	X	X		X	X				X	
7. DISASSEMBLE & RESTOW EXPERIMENT COMPONENTS		X	X		X	X	X	X	X	X		X	X	TBD				
8. SHUT DOWN RMS			X		X		X	X	X			X	X					

and experiment during the experiment operations. The specially designed container interface with the orbiter structure will normally be through standard sill latches and keel fittings. These standard fittings are sized to provide necessary load restraints in the X, Y, and Z directions (Figure 7-35).

The container must provide a number of electrically actuated flight restraint devices for holding the experiment structure and components within the container. These will be released as necessary during experiment deployment operations and again attached at the conclusion of the experiment when the structure and components are again packaged for the return flight. The operation of the various latches will be controlled from the AFD. Therefore orbiter AFD console, electrical power, electrical central and data processing and software interfaces will be required. Special software may need development in order to minimize the number of data and control lines between the orbiter bay and the total of all the payload segments of the Experiment 2 orbiter flight.

The experiment container design for attachment to the orbiter must be compatible with longeron sill fitting attachment points available. The design also must be compatible with the ground handling equipment for efficient orbiter loading.

Equipment Module and Umbilical

The major equipment module for Experiment 2 is a separable experiment container which is attached to the deployed structure during the experiment operations. The unit will be electrically powered and controlled to provide appropriate excitation vibration to the experiment structure. Therefore this unit also will require interface connection with the orbiter electrical power and controls and consequently interface with the AFD console. After the module is attached to the structure, the electrical and electrical control umbilical must be connected to the module. The umbilical also must interface with the container and from the container to the orbiter payload bay electrical and control access accommodations.

Holding and Positioning Aid

Not used on Experiment 2.

RMS

Standard RMS with its standard software controls is believed adequate for Experiment 2.

Special End Effector (SEE)

The Experiment 2 Structure and Equipment module will be designed to be compatible with the standard RMS end effector. A SEE may be required for handling of a separable umbilical installation if this is a part of the experiment operations to be tested. Using EVA for umbilical installation may reduce the need for a SEE. When the special end effector is specified, its primary interface will be with the RMS standard end effector (to be attached

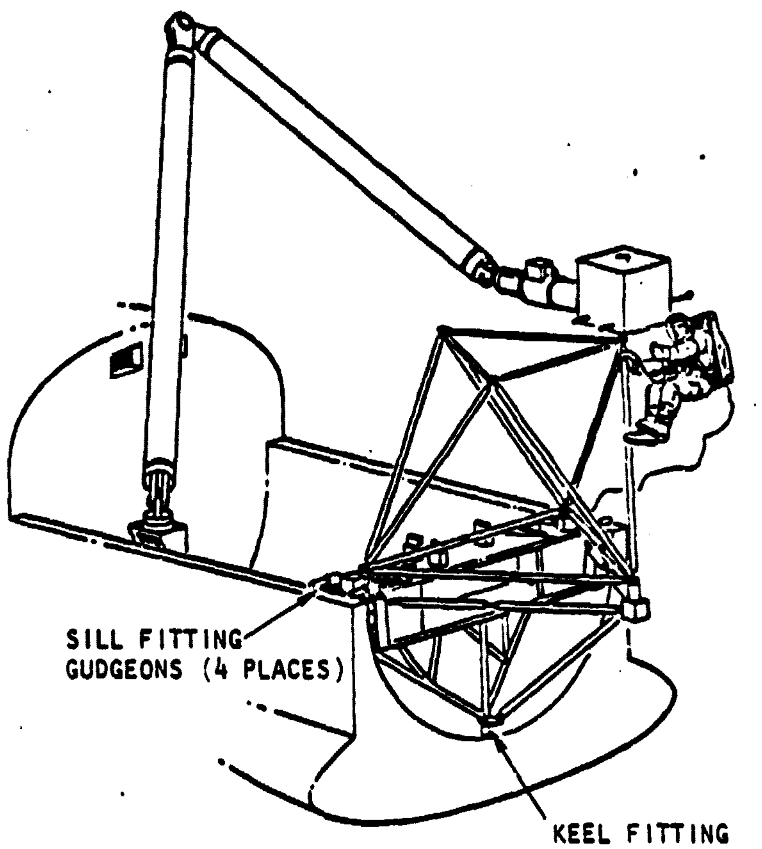


Figure 7-35. Experiment 2 Structure and Container

on orbit) or it could be installed in place of the "standard" if this were advantageous for the total mission payload. The secondary orbiter interface considerations are indicated on the summary table.

Manned Maneuvering Unit

The MMU interface with the orbiter would be with orbiter provision for storage in the payload bay and with provision for resupply of consumables for the MMU units. Secondary considerations would of course be those connected with the EVA astronaut entry and egress to the orbiter airlock.

Operations

The details of the estimated operations required to perform Experiment 2 are listed in the previous mission scenario, Section 7.1.2. The major operational interfaces with the orbiter systems are indicated in Table 7-7. The payload bay pallet/container subsystem would be involved in activities such as items 1, 3, 4 and 7 of the listing. These are releasing and unpacking the experiment container, releasing and deploying the structural elements, installing the shaker module, and restowing the experiment components after test completion.

Seven of the orbiter systems and subsystems shown on Table 7-2 are estimated to be supporting all of the eight operational activities: (1) RMS, (2) AFD controls and displays, (3) data processing and software, (4) electrical power distribution and controls, (5) electrical power, (6) AFD console, and (7) the AFD crew.

Experiment operations planned include testing of assembly activities such as module installation during orbiter stabilization or orientation maneuvers. This activity would then involve carefully controlled and coordinated use of the orbiter RCS.

The preliminary weight estimates for the cargo manifest, Table 7-8 indicate that the total weight will be approximately 1800 lb, including the support cradle.

The on-orbit operations will demand significant power and energy demands from the orbiter. The RMS motors and its heater will be the major user together with the CCTV and lights. The power used by the RMS has been average, as 50% duty cycle for the heaters and a conservative nearly 100% duty cycle power for the motor drives. The average power and energy requirements for various operations is shown in Table 7-9. The average energy for the experiment 2 mission is 35628 K Joules, Table 7-10, which for this missions equates to an average power of 1.25 kW.

Table 7-8. Cargo Manifest—Experiment No. 2

<u>STRUT MODULE (240 LB)</u>

6 NON-HINGED STRUTS
6 HINGED STRUTS
6 MULTIPLE JOINT UNIONS
6 HINGES AND DAMPERS
1 MODULE ADAPTER UNION
2 TAKE-UP REELS AND CABLE
6 LANYARDS
4 BERTHING BALL ENDS

<u>SUBSYSTEM MODULE (170 LB)</u>

1 STRUCTURAL CONTAINER
2 SINUSOIDAL SHAKER UNITS
1 RANDOM VIBRATION GENERATOR
1 MODULE-TO-STRUT ADAPTER

<u>CRADLE ASSEMBLY (350 LB)</u>

MAIN STRUCTURE
3 ATTACHMENT TRUNNIONS
3 STRUT MODULE BERTHING LATCHES
1 REAR STAY LATCH
2 LID RESTRAINT LATCHES
2 SHAKER MODULE RESTRAINT LATCHES
1 END ADAPTER RESTRAINT LATCH

<u>MISCELLANEOUS (1050 LB)</u>

1 RMS END ADAPTER
12 PIEZO-ELECTRIC ACCELEROMETERS
1 SIGNAL RELAY BOX
1 POWER & SIGNAL UMBILICAL
1 POWER AMP; 1 LOOP AMP; 1 TAPE RECORDER
2 EVA SUITS
3 EVA

TOTAL WEIGHT 1810 LB

Table 7-9. Basic Power Building Blocks

FUNCTION		DURATION (SEC)	AVG. PWR (kW)	ENERGY (kJ)
1. RMS GRASP OBJECT		300	0.845 0.525	253.5 151.5
2. REMOTE RELEASE OF LATCHES FROM CREW CABIN		30	0.02	0.6
3. RMS REMOVE AN OBJECT, ROTATE IT THROUGH 180°, AND PUT BACK IN POSITION		1,200	0.845 0.525	1,014.0 630.0
4. RMS REMOVE OBJECT AND STOW IN CARGO BAY		1.200	0.845 0.525	1,014.0 630.0
5. RMS RELEASE OBJECT AND BACK AWAY		50	0.845 0.525	50.7 31.5
6. WRIST TV & HEATER	(13) (20)	-	0.023	
7. ELBOW TV CAMERA, HEATER AND PAN/TILT AND HEATER	(13) (20) (8) (6)	-	0.057	
8. BULKHEAD TV CAMERA HEATER, PAN/TILT AND HEATER		-	0.057	
9. (6) CARGO BAY LITES @ 200 W		-	1.200	
10. (3) CHERRY PICKER LITES @ 60 W		-	1.800	
11. (1) CARGO BAY LITE AT CREW COMP AFT BULKHEAD @ 200 W		-	0.200	

Table 7-10. Mission Power Allocation - Experiment 2

	ITEM	TIME (MIN.)	AVG. PWR (kW)	ENERGY (kJ)
1.	RMS	25.25	0.845	1,280
	RMS WRIST LITE	8.42	0.173	87
	AFT CREW STA. LITE	8.42	0.200	101
	FWD TV CAMERA & HTR.	25.25	0.023	35
	WRIST TV & HTR.	25.25	0.057	86
	ELBOW TV & HTR.	25.25	0.057	86
2.	RMS	30.5	0.845	1,546
	RMS WRIST LITE	10.17	0.173	105
	AFT CREW STA. LITE	10.17	0.200	122
	THREE CARGO BAY LITES	10.17	0.600	366
	FWD TV CAMERA & HTR.	30.5	0.057	104
	WRIST TV & HTR.	30.5	0.023	42
	AFT TV CAMERA & HTR.	15.25	0.057	52
	ELBOW TV & HTR.	30.5	0.057	104
3.	RMS	78.0	0.845	3,954
	RMS WRIST LITE	26.0	0.173	279
	AFT CREW STA. LITE	26.0	0.200	312
	THREE CARGO BAY LITES	26.0	0.600	936
	FWD TV CAMERA & HTR.	78.0	0.057	266
	WRIST TV & HTR.	78.0	0.023	107
	AFT TV CAMERA & HTR.	39.0	0.057	133
	ELBOW TV & HTR.	78.0	0.057	266
4.	RMS	25.28	0.845	1,280
	RMS WRIST LITE	8.42	0.173	87
	AFT CREW STA. LITE	8.42	0.200	101
	THREE CARGO BAY LITES	8.42	0.600	303
	FWD TV CAMERA & HTR.	25.25	0.057	86
	WRIST TV & HTR.	25.25	0.023	35
	AFT TV CAMERA & HTR.	12.63	0.057	43
	ELBOW TV & HTR.	25.25	0.057	86
5a.	RMS	63.0	0.845	3,194
	RMS WRIST LITE	21.0	0.173	218
	AFT CREW STA. LITE	21.0	0.200	25
	WRIST TV CAMERA & HTR.	63.0	0.023	87
	ELBOW TV & HTR.	63.0	0.057	215
	SHAKER	60.0	0.035	126
	ELECTRONICS	63.0	0.010	38
5b.	RMS	52.50	0.845	2,662
	RMS WRIST LITE	17.50	0.173	182
	AFT CREW STA. LITE	17.50	0.200	210
	WRIST TV & HTR.	52.50	0.023	72
	ELBOW TV & HTR.	52.50	0.057	180
	AFT TV & HTR.	26.25	0.057	90
	FWD TV & HTR.	26.25	0.057	90
	SHAKER	46.0	0.035	96
	ELECTRONICS	52.50	0.010	32

Table 7-10. Mission Power Allocation - Experiment 2 (Cont.)

ITEM		TIME (MIN.)	AVG. PWR (kW)	ENERGY (kJ)
6.	RMS	72.0	0.845	3,650
	RMS WRIST LITE	24.0	0.173	249
	AFT CREW STA. LITE	24.0	0.200	288
	WRIST TV & HTR.	72.0	0.023	99
	ELBOW TV & HTR.	72.0	0.057	246
	AFT TV & HTR.	36.0	0.057	123
	FWD TV & HTR.	36.0	0.057	123
	THREE CARGO BAY LITES	24.0	0.600	864
7.	RMS	119.25	0.845	6,046
	RMS WRIST LITE	39.75	0.173	412
	AFT CREW STA. LITE	39.75	0.200	477
	WRIST TV & HTR.	119.25	0.023	164
	ELBOW TV & HTR.	119.25	0.057	407
	AFT TV & HTR.	59.63	0.057	204
	FWD TV & HTR.	59.63	0.057	204
	THREE CARGO BAY LITES	39.75	0.600	1,431
8.	RMS	9.5	0.845	482
	RMS WRIST LITE	3.15	0.173	33
	AFT CREW STA. LITE	3.15	0.200	38
	WRIST TV & HTR.	9.5	0.023	13
	ELBOW TV & HTR.	9.5	0.057	32
	FWD TV & HTR	9.5	0.057	32
	THREE CARGO BAY LITES	3.15	0.600	113
			Total KJ =	35,628

7.2 EXPERIMENT NO. 2 (PRIME) - DEPLOYED/ASSEMBLED STRUCTURAL DYNAMICS EXPERIMENT VARIATION

The experiment is intended to be a down-sized version of Experiment No. 2. It will verify the majority of structural dynamic test objectives. Conducted for Experiment No. 2 while at the same time being a less complex and costly experiment. Several of the important test objectives involving space construction and RMS effectiveness will not be addressed. This test concept was suggested by the NASA/JSC. It entails the vibration testing of a simple geometric structure which is deployed by the RMS pulling the stowed test module out of its container, Figure 7-36.

7.2.1 Configuration Description

The experiment hardware consists of a deployable structure module, shaker module, docking interface, experiment container and vibration measurement sensors.

The deployable structure module as suggested by NASA/JSC would consist of double hinged struts and fold into the package as shown in Figure 7-37. Each hinge would have a self-locking device to allow the struts to be rigid when they are fully deployed. No deployment energy is required by the hinge mechanism since deployment is accomplished using the RMS to stretch the structure to its deployed arrangement. The struts are fabricated from light weight graphite/epoxy composite material to represent typical structural concepts to be used for LSS construction. The top apex of the deployable structure is provided with an RMS grapple point to aid in deployment. The other apex consists of the passive docking interface structure.

Figure 7-36 shows the deployable structure fitted to a simplified test stand attached to the side of the orbiter cargo bay. This test stand could be enlarged to provide the container and tie-down restraints for the deployable structure during the ascent to and return from orbit. The container for the deployable structure and the shaker module will have to be mounted onto an available payload pallet or provide its own support cradle across the cargo bay.

The vibration testing will require a shaker module attached to the deployable structure. This module can be smaller than proposed in Experiment No. 2 since, the module is not required to simulate a subsystem module. In fact, the shaker module can be directly attached to the apex of the deployable structure. The RMS grapple point will then be attached to the top of the shaker module. The electrical and signal lines are pre-attached to the structure and there is a jumper interface (coiled pig-tail) across the docking interface. This will allow the structure to be lifted clear of the container by a couple of feet while at the same time still retain power and signal connection.

After the vibration experiment the deployed structure is retracted. This operation will require the RMS and an astronaut to manipulate a series of lanyards to fold the hinges. These folds are shown in Figure 7-37 to involve both inward and outward motion of the various sets of hinges.

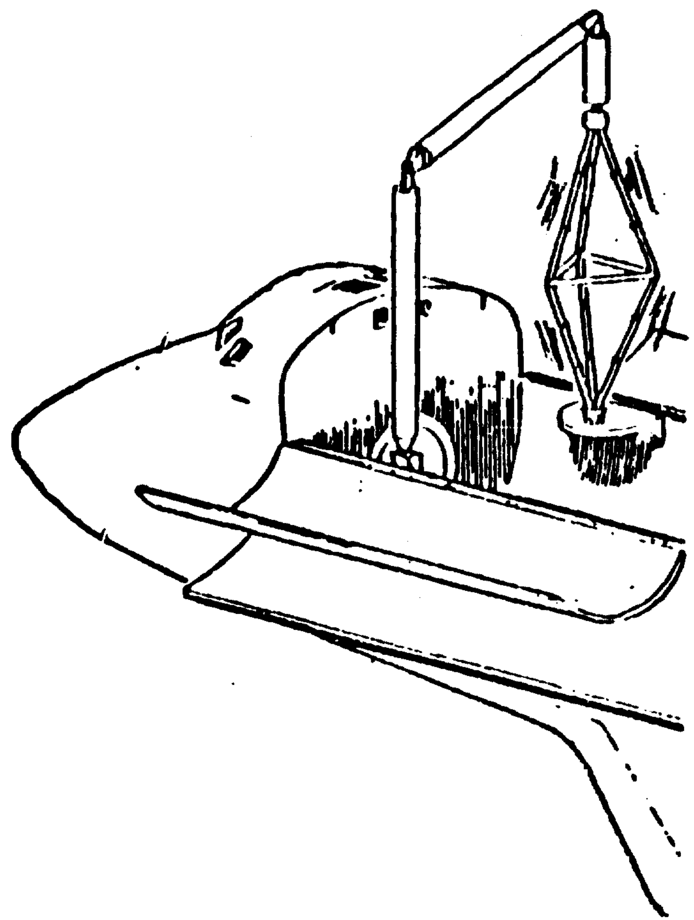


Figure 7-36. Flight Experiment No. 2 (Prime)

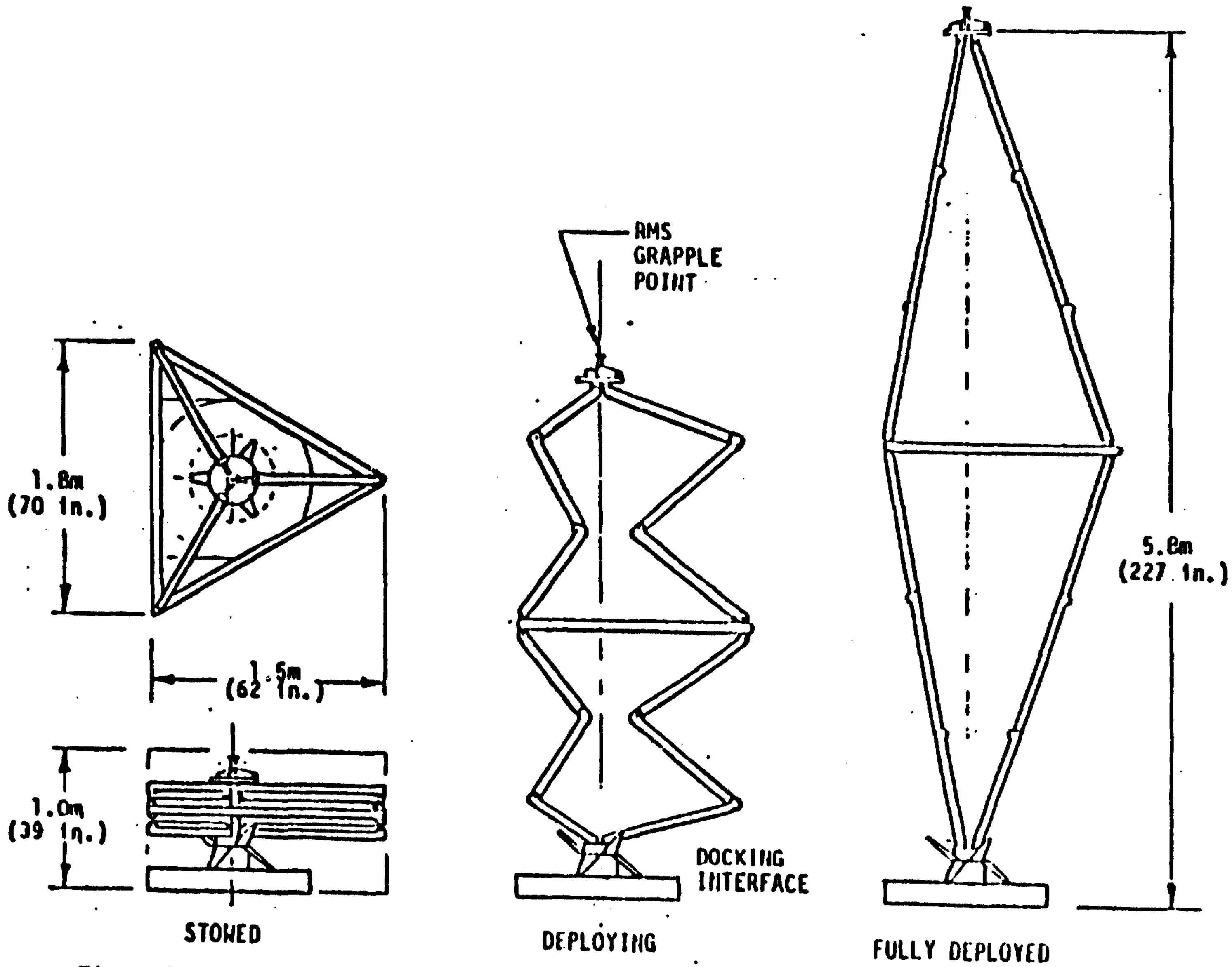


Figure 7-37. Experiment No. 2 (Prime)—Deployable Structure Module

This design concept will require a complex arrangement of lanyards, and/or mechanisms to effect this retraction operation.

It should be noted that the deployed structure for Experiment No. 2 (prime) does not differ functionally from the structure in Experiment No. 2 (Figure 7-38). If the four-sided, double ended pyramid of Experiment No. 2, laying on its side in Figure 7-38 is attached to one corner (node 2) opposite to the shaker module and placed upright to the starboard attachment fitting, it would duplicate the Experiment No. 2 (Prime) configuration. Therefore, all other structural details and interfaces are similar and have been discussed in the Experiment No. 2 section.

7.2.2 Mission Scenario

The major test objectives for this scaled down experiment are included in Experiment No. 2 test objectives. Therefore, the mission operations will be similar and the time estimates for each individual operation element are those quoted in Table 7-4.

The total mission has been divided into the same eight (8) major operational tasks. A brief description of each task is outlined in the following paragraphs.

Task 1 prepares the RMS for operation and will power up, release the RMS from its hold down fitting and perform a checkout of its operation. The time allotted for this checkout operation is 24 minutes.

Task 2, the release and unpacking of the experiment container, is accomplished using the RMS. The container box will be operated by remotely releasing the latches, and with the RMS raising the lid. Total time involved for the task should not exceed 7.00 minutes.

The structure module is packaged inside the container during the orbiter ascent into orbit. The RMS end effector, first releases the restraining clamps around the structure module and withdraws them from the container. Next the struts are attached to a test stand positioned at the starboard side of the cargo bay. Deployment of the structure module is assisted by using the RMS to release the restraining fitting that connects the end unions together. A gradual deployment is controlled by the viscous dampers attached to the hinges. After full deployment of the structure module, the RMS is used to test whether the hinges are fully locked. The time for the deployment operation is approximately 35 minutes.

It has been assumed for Experiment No. 2 (Prime) that the shaker module is stowed separately from the structure module. The actual attaching of the shaker module is one of the supporting test objectives for this experiment. It is possible that further simplification could be achieved by having the shaker module already attached to the apex node and the whole experiment deployed in a "Jack-in-the-box" fashion. It is felt that several useful test objectives associated with space construction operations would not be verified by this further simplification.

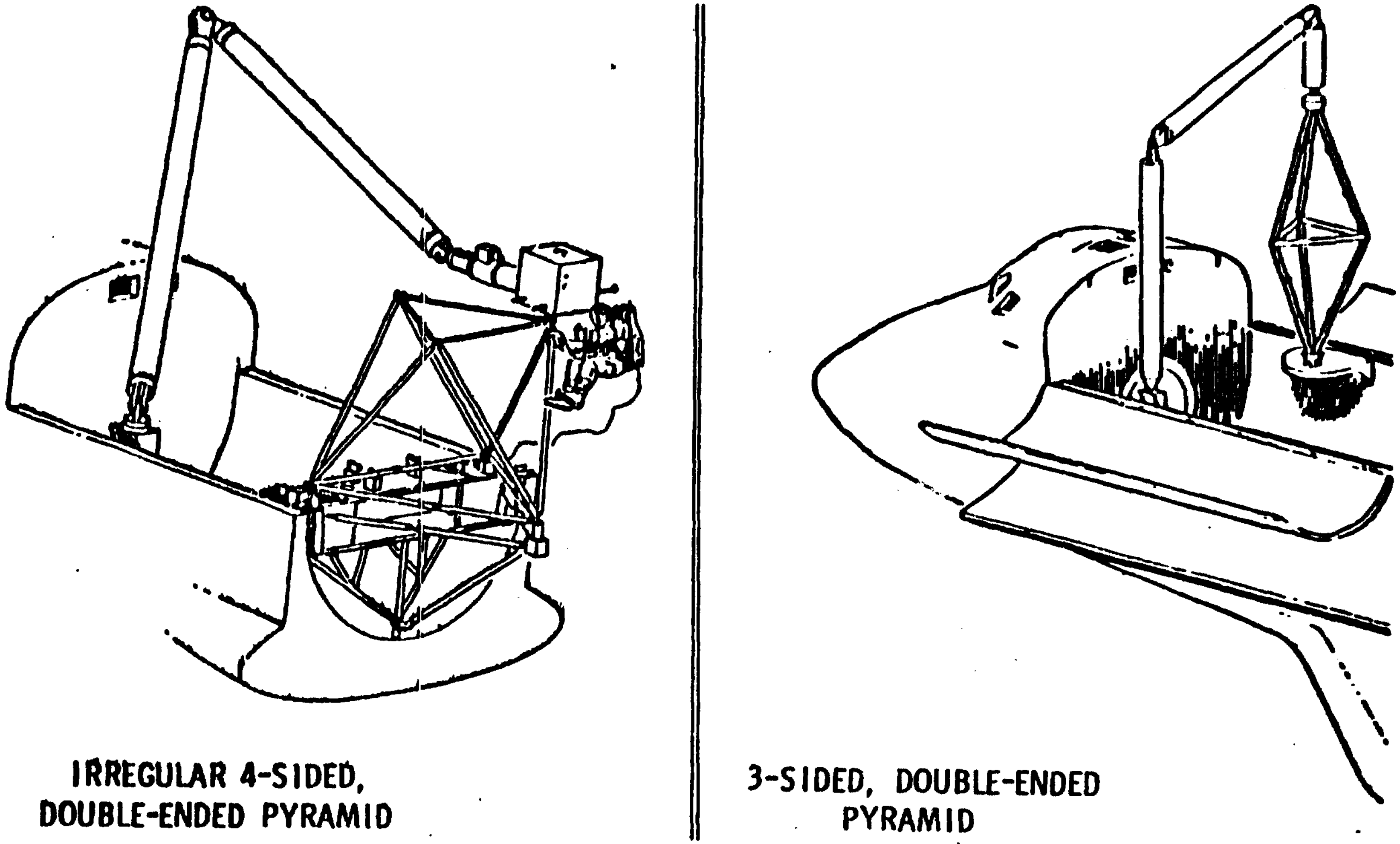


Figure 7-38. Comparison of Structure Modules between Experiments

The installation and activation of the shaker module is identical to the procedure outlined for Experiment No. 2 and the time involved is 25.25 minutes. The actual electrical connection of the shaker to apex node, and structure module to the power umbilical at the base has been considered as an RMS activity. It is possible that a simpler design and operational procedure would be to utilize the EVA astronaut to undertake these operations. The time estimates would not be significantly different.

The dynamic test experiment is conducted initially with the structure module attached to the test stand. A series of frequency sweeps are performed and test measurements are recorded of the vibrational behavior of the structure module. The vibrations are allowed to decay in order to obtain information on the damping characteristics of the struts, joints and hinges associated with a lightweight flexible structure. Next the RMS is used to grasp the shaker module and lift the structure module from its test stand With the shaker and structure module suspended from the RMS the experiment is considered to be in a psuedo "free free" suspension mode and the excitation and damping tests are repeated again. If the vibration tests are preplanned and programmed they should be completed in about 80 minutes.

The next part of the mission is concerned with understanding the effects on construction induced by orbiter disturbances. Task 6 will use the RMS to berth the structure module with the universal-type docking interface mounted on the test stand. The docking operation is repeated several times with the orbiter in different attitude hold modes and orientations. This will indicate the induced dynamic interaction between the orbiter and the RMS performing precision positioning and alignment operations that are important aspects of space construction activity. Forty-eight (48) minutes has been allocated for this phase of the mission. If there is time available, it would be extremely beneficial if these operations are extensively repeated to obtain statistical data on settling time and time required to complete precision positioning under adverse conditions.

The experiment breakdown and restowing will be accomplished using both the RMS and astronaut working in close cooperation with each other. The EVA astronaut is needed to disconnect the power and signal lines and release the shaker module from the apex node. The current design shown in Section 7.1.1 for the module attachment fitting requires the astronaut with a special hand operated tool attached to the fitting to withdraw the probe.

Due to the double hinge per strut arrangement of this configuration, the packaging arrangement necessitates the set of three hinges next to the top and bottom nodes to be folded outwards while the remaining hinges fold inwards. The inwards and outwards movement is difficult to achieve with a simple lanyard operation similar to Experiment No. 2 and the time for this task is estimated to be 63 minutes. With the final task of shutdown and securing the RMS (9.5 minutes) the total mission time for Experiment No. 2 (Prime) is expected to be nearly five (5) hours (Table 7-12).

Table 7-11. Time Estimates for 8 Operational Tasks in Mission Scenario

1. PREPARING RMS FOR OPERATION

	DESCRIPTION OF OPERATION	TIME (MINS)
1.1	PREPARE GPCs FOR RMS OPERATION	3.5
1.2	MANEUVER TO DEPLOYMENT ATTITUDE	6.5
1.3	POWER UP MANIPULATOR ARM HEATERS	(6.5)
1.4	POWER UP, CHECK OUT CCTV/LIGHTS	(5.0)
1.5	POWER UP MANIPULATOR - UNLOCK HAND CONTROLLERS	(1.0)
1.6	STABILIZE - FREE DRIFT - RCS OFF	(1.0)
1.7	PERFORM MANIPULATOR ARM STATIC CHECKOUT	5.0
1.8	ROTATE MANIPULATOR ARM - RELEASE RESTRAINTS	2.0
1.9	SELECT AUTO PROGRAM - DEPLOY MANIP.ARM	1.5
1.10	PERFORM MANIP. FUNCTIONAL CHECKS	5.0
1.11	SELECT/VERIFY MANUAL AUG. CONTROL	0.25
	TOTAL TIME LAPSED	24 MINS

2. RELEASE AND UNPACKING OF EXPERIMENT CONTAINERS

	DESCRIPTION OF OPERATION	TIME (MINS)
2.1	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
2.2	MOVE END EFFECTOR TO TOP LID OF STRUT CONTAINER BOX	1.50
2.3	DOCK END EFFECTOR WITH ATTACHMENT POINT ON LID AND GRAPPLE	2.50
2.4	RELEASE CONTAINER LID HOLD DOWN LATCHES	0.25
2.5	MOVE END EFFECTOR TO OPEN CONTAINER LID	1.50
2.6	RELEASE GRAPPLE FIXTURE ON LID AND BACK AWAY	1.00
	TOTAL TIME	7.00

Table 7-11. Time Estimates for 8 Operational Tasks in Mission Scenario (Cont.)

3. RELEASE AND DEPLOYMENT OF STRUCTURAL ELEMENTS

	DESCRPTION OF OPERATION	TIME (MINS)
3.1	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.2	M/A MODE MOVE END EFFECTOR TO STOWED STRUTS	1.50
3.3	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.4	DOCK END EFFECTOR TO GRAPPLE FIXTURE ON STOWED STRUTS	2.50
3.5	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.6	RELEASE LATCHES AND RESTRAINING CLAMPS AROUND STRUTS	0.25
3.7	WITHDRAW STRUTS FROM INSIDE OF CONTAINER BOX	1.50
3.8	MOVE STRUTS TO STARBOARD SIDE OF CARGO BAY	1.50
3.9	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.10	ROTATE STRUTS TO VERTICAL POSITION	0.50
3.11	DOCK STREUTS WITH STARBOARD TEST STAND AND LOCK	2.50
3.12	RELEASE GRAPPLE FIXTURE AND BACK AWAY	1.00
3.13	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.14	MOVE END EFFECTOR TO OTHER END OF STRUT PACKAGE	1.50
3.15	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
3.16	DOCK TO GRAPPLE FITTING USED FOR RESTRAINING END UNIONS	2.50
3.17	RELUASE UNION RESTRAINTS AND BACK AWAY RMS	1.00
3.18	ALLOW STRUTS TO DEPLOY AND DEPLOYMENT HINGES TO LOCK	2.00
3.19	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.20	MOVE TO DEPLOYMENT HINGE #1 AND #2	1.50
3.21	ASSURE DEPLOYMENT HINGE #1 AND #2 ARE LOCKED	1.00
3.22	MOVE TO OTHER 5 DEPLOYMENT HINGE PAIRS & ASSURE HINGES ARE LOCKED	2.50
	TOTAL TIME	35.00

Table 7-11. Time Estimates for 8 Operational Tasks in Mission Scenario (Cont.)

4. INSTALLATION AND ACTIVATION OF SHAKER MODULE

	DESCRIPTION OF OPERATION	TIME (MINS)
4.1	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.2	MOVE END EFFECTOR TO SHAKER MODULE ATTACHED TO CONTAINER INSIDE OF CARGO BAY	1.50
4.3	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.4	DOCK AND GRAPPLE SHAKER MODULE	2.50
4.5	RELEASE MODULE/FIXTURE ATTACHMENT MECHANISM	0.25
4.6	BACK MODULE AWAY FROM HOLDING FIXTURE	1.00
4.7	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.8	MOVE SHAKER MODULE TO APEX NODE OF STRUCTURAL MODULE	1.50
4.9	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.10	DOCK SHAKER MODULE TO STRUCTURAL NODE	2.00
4.11	RELEASE MODULE AND BACK AWAY	1.00
4.12	MOVE AND CONNECT ELECTRICAL CONNECTION TO SHAKER MODULE	2.00
4.13	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.14	MOVE RMS TO STARBOARD ATTACHMENT FIXTURE	1.50
4.15	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.16	DOCK TO ELECTRICAL UMBILICAL	2.50
4.17	CONNECT UMBILICAL TO STRUT MODULE	2.00
4.18	RELEASE UMBILICAL AND BACK AWAY	1.00
4.19	PERFORM ELECTRICAL AND SIGNAL CHECKS ON CONNECTIONS AND SHAKER MODULE	5.00
	TOTAL TIME	25.25

Table 7-11. Time Estimates for 8 Operational Tasks in Mission Scenario (Cont.)

5. DYNAMIC EXPERIMENT AND MEASUREMENT

	DESCRIPTION OF OPERATION	TIME (MINS)
5.1	PREPARE EQUIPMENT AND RECORDING SENSORS	2.00
5.2	ACTIVATE SHAKER MODULE	1.00
5.3	CONDUCT FREQUENCY SWEEP TO EXCITE SERIES OF STRUCTURAL MODES AND RECORD TEST DATA	10.00
5.4	INCREASE ENERGY INPUT AND PERFORM SECOND FREQUENCY SWEEP - REPEAT ENERGY INCREASE SEVERAL TIMES - MISSION PERMITTING	30.00
5.5	SELECT RMS ORBITER COORD. REF. SYSTEM	0.25
5.6	MOVE RMS TO TOP OF SHAKER MODULE	1.50
5.7	SELECT END EFFECTOR COORD. REF. SYSTEM	0.25
5.8	DOCK AND GRAPPLE FOR SHAKER MODULE	2.50
5.9	RELEASE BERTHING INTERFACE BETWEEN STRUT MODULE AND TEST STAND	0.25
5.10	SELECT ORBITER REF. COORD. SYSTEM	0.25
5.11	RAISE STRUT MODULE AWAY FROM CARGO BAY	1.50
5.12	ACTIVATE SHAKER MODULE	1.00
5.13	CONDUCT SERIES OF FREQUENCY SWEEPS AT DIFFERENT ENERGY LEVELS AND RECORD TEST DATA	30.00
	TOTAL TIME	80.50

Table 7-11. Time Estimates for 8 Operational Tasks in Mission Scenario (Cont.)

6. MODULE RELEASE, TRANSLATION AND REDOCKING

	DESCRIPTION OF OPERATION	TIME (MINS)
6.1	SELECT ORBITER REF. COORD. SYSTEM	0.25
6.2	MOVE END EFFECTOR TO STRUT NODE	1.50
6.3	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
6.4	DOCK WITH GRAPPLE FEATURE AT NODE	2.50
6.5	RELEASE LATCH RESTRAINING STRUT MODULE TO TEST STAND	0.50
6.6	SELECT ORBITER REF. COORD. SYSTEM	0.25
6.7	MOVE STRUT MODULE AWAY FROM ORBITER	1.50
6.8	MOVE STRUT MODULE TO ATTACHMENT FIXTURE FOR BERTHING OPERATION	1.50
6.9	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
6.10	PERFORM BERTHING OPERATION WITH DOCKING INTERFACE ON TEST STAND	2.50
6.11	RELEASE MODULE AND BACK AWAY	1.00
	SUB TOTAL	12.00
6.12	REPEAT ABOVE SEQUENCE OF OPERATIONS WITH ORBITER IN A CONTROLLED ATTITUDE MODE WITH VERNIER IN RCS FIRINGS	12.00
6.13	REPEAT ABOVE SEQUENCE OF OPERATIONS AT DIFFERENT ORIENTATIONS	24.00
	TOTAL TIME	48.00

Table 7-11. Time Estimates for 8 Operational Tasks in Mission Scenario (Cont.)

7. EXPERIMENT BREAKDOWN AND RESTOWING

	DESCRIPTION OF OPERATION	TIME (MINS)
7.1	SELECT ORBITER COORD. REF. SYSTEM	0.25
7.2	MOVE RMS END EFFECTOR TO SHAKER MODULE	1.50
7.3	DOCK AND GRAPPLE WITH ELECTRICAL CONNECTOR	2.50
7.4	DISCONNECT ELECTRICAL AND SIGNAL CONNECTORS	2.00
7.5	RELEASE CONNECTORS AND BACK AWAY	1.00
7.6	DOCK AND GRAPPLE WITH SHAKER MODULE	2.50
7.7	RELEASE ATTACHMENT OF MODULE FROM NODE	5.00
7.8	BACK SHAKER AWAY FROM STRUT MODULE	1.00
7.9	SELECT ORBITER REF. COORD. SYSTEM	0.25
7.10	MOVE SHAKER MODULE TO CONTAINER	1.50
7.11	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.12	DOCK SHAKER TO FIXTURE INSIDE CONTAINER	2.50
7.13	ACTIVATE HOLD DOWN LATCHES TO SHAKER	0.25
7.14	RELEASE RMS FROM SHAKER AND BACK AWAY	1.00
7.15	SELECT ORBITER REF. COORD. SYSTEM	0.25
7.16	MOVE END EFFECTOR TO LANYARD PULLUP POSITION	1.50
7.17	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.18	DOCK WITH LANYARD MECHANISM	2.50
7.19	WITH EVA ASSIST REEL IN LANYARD, RELEASE HINGE JOINTS AND RETRACT STRUT MODULE	0.00
7.20	LOCK LANYARD MECHANISM	0.25
7.21	RELEASE RMS FROM LANYARD MECHANISM AND BACK AWAY	1.00
7.22	MOVE END EFFECTOR TO TOP LID OF STRUT CONTAINER, DOCK, RELEASE LATCHES, OPEN CONTAINER LID AND SECURE	6.00
7.23	RELEASE RMS FROM CONTAINER LID	0.25
7.24	MOVE TO STARBOARD FIXTURE, DOCK WITH STRUT MODULE RELEASE ATTACHMENT LUTCHES, AND STOW MODULE IN STRUT CONTAINER	1.50
7.25	LATCH BUNDLED STRUT MODULE SAFELY INTO CONTAINER	2.00
7.26	MOVE RMS TO LID, DOCK AND RELEASE LID, CLOSE LID DOWN AND ACTIVATE LATCHES	6.00
	TOTAL TIME	63.00

Table 7-11. Time Estimates for 8 Operational Tasks in Mission Scenario (Cont.)

8. RMS SHUT-DOWN

	DESCRIPTION OF OPERATION	TIME (MINS)
8.1	RETRACT ARM TO IC FOR AUTO	0.50
8.2	SELECT AUTO PROGRAM TO MOVE ARM TO PRE-STOW	0.25
8.3	MONITOR AUTO MANIP. ARM MOVEMENT TO PRE STOW	0.50
8.4	SELECT DIRECT MANIPULATOR ARM DRIVE	0.25
8.5	STOW MANIP. ARM IN RESTRAINTS. ROTATE TO STOWED POSITION	2.00
8.6	PERFORM POST-OPNS MANIP. STATUS CHECK	5.00
8.7	SHUT DOWN MANIP. ARM HEATERS. LOCK HAND CONTROLS	0.50
8.8	POWER DOWN CCTV AND LIGHTS	0.50
	TOTAL TIME LAPSED	9.50

Table 7-12. Summary of Mission Timeline for Experiment 2 Prime

	DESCRIPTION OF OPERATION	TIME (MINS)
1.	PREPARING RMS FOR OPERATIONS	24.00
2.	RELEASE AND UNPACKING OF EXPERIMENT CONTAINER	7.00
3.	RELEASE AND DEPLOYMENT OF STRUT MODULE	35.00
4.	INSTALLATION AND ACTIVATION OF SHAKER MODULE	25.25
5.	DYNAMIC EXPERIMENT AND MEUSUREMENTS	80.50
6.	MODULE RELEASE, TRANSLATION AND REDOCKING	48.00
7.	EXPERIMENT BREAKDOWN AND RESTOWING	63.00
8.	RMS SHUTDOWN	9.50
	TOTAL TIME	292.25 MINS (4.9 HRS)

7.2.3 Experiment No. 2-Prime/Orbiter Interface

Experiment No. 2 (Prime) provides a lower cost version of the previously described Experiment No. 2. Simplification is planned in experiment design and also in experiment operations. For Experiment No. 2 (Prime) the general concept is to eliminate separable experiment components. The equipment module will be mounted on the structural framework and pre-wired prior to launch. Preparation for experiment dynamic operations will then consist of withdrawing the folded deployable structure from its packaged configuration to a deployed configuration using the RMS, EVA operations will not be required for umbilical connection as is estimated for Experiment No. 2.

The shaker module can then be activated as soon as the locking of the deployed structure is verified. When the vibration test sequence is completed, testing of module release, translation and redocking can be accomplished but with elimination of the electrical umbilical connection.

7.2.3.1 Experiment Components

The Experiment No. 2 (Prime) component interfaces with the orbiter is summarized in Table 7-13. Only five of the generic listing of components are required for this experiment. The umbilical, HAPA, SEE, MMU, and cherry picker are not scheduled for use in Experiment No. 2 (Prime). The interface description for the five actual components is similar to those given for Experiment No. 2 (Section 7.1.4) and will not be repeated here.

7.2.3.2 Operations

The details of the estimated operations required to perform Experiment No. 2 (Prime) are given in the mission scenario section (Section 7.2.2). The major operational interfaces with the orbiter systems are shown in Table 7-13. As mentioned previously in the introduction to this section, the experiment operations planned for the Experiment No. 2 (Prime) concept are a simplified version of the Experiment No. 2. The second operational category from the Experiment No. 2 listing—Release and Unpack Experiment Containers—was eliminated from the Experiment No. 2 (Prime) version. The other operational areas shown in the table are similar to the descriptions given in Section 7.1.4.

This experiment will weigh considerably less than experiment 2. If there is a full cradle as suggested. Table 7-14 indicates that the total weight estimate is about 800 lb.

Table 7-13. Experiment No. 2 (Prime) Orbiter Interface Matrix

	SELECTED ORBITER SYSTEMS AND SUBSYSTEMS			AVIONICS														
EXPERIMENT COMPONENTS AND OPERATIONS	PAYLOAD BAY STRUCTURE	PAYLOAD BAY PALLET	ORBITER RMS	COMM. AND TRACKING	DISPLAYS AND CONTROLS	CAUTION AND WARNING	DATA PROC. & SOFTWARE	ELEC. POWER DIST. & CONTR.	ELECTRICAL POWER	PAYLOAD BAY LIGHTING	CLOSED-CIRCU.? TV (CCTV)	AFT FLIGHT DECK CONSOLE	AFT FLIGHT DECK CREW	EVA CREW	MANNED MANEUVERING UNIT	CHERRY PICKER	REACTION CONTR. SYSTEM (RCS)	P/L GROUND HANDLING SYS.
COMPONENTS																		
1. DEPLOYABLE STRUCTURE		X					X	X	X			X						
2. EXPERIMENT CONTAINER	X	X						X	X			X						X
3. CONTAINER SUPPORT	X	X			X	X						X						
4. EQUIPMENT MODULE	X	X			X	X	X	X	X	X		X						
5. UMBIL., WIRE HARNESS, ETC																		
6. HAND. & POS. AID (HAPA)																		
7. RMS	X		–		X	X	X	X	X		X	X						
8. SPEC. END EFFECTOR (SEE)																		
9. MANNED MANEUV. UNIT (MMU)																		
10. CHERRY PICKER																		
OPERATIONS																		
1. PREPARE RMS FOR OPERA.			X		X		X	X	X			X	X					
2. RELEASE & DEPLOY STRUCTURAL ELEMENTS		X	X		X	X	X	X	X			X	X					
3. ACTIVATE SHAKER MODULE					X		X	X	X			X	X					
4. PERFORM DYNAMIC EPMT OPS, RECORD MEASUREMENTS				X	X	X	X	X	X	X		X	X					
5. PERF. MODULE RELEASE TRANSLATION & REDOCKING			X		X	X	X	X	X	X		X	X					
6. RESTOW EXPMT COMPONENTS		X	X		X	X	X	X	X	X		X	X					
7. SHUT DOWN RMS			X		X		X	X	X			X	X					

Table 7-14. Cargo Manifest—Experiment 2 Prime

STRUT MODULE (115 LB)

3 NON-HINGED STRUTS
6 HINGED STRUTS
5 MULTIPLE JOINT UNIONS
12 HINGES AND DAMPERS
1 MODULE ADAPTER UNION
2 TAKE-UP REELS AND CABLE
6 LANYARDS
1 DOCKING INTERFACE (PASSIVE)

SUBSYSTEM MODULE (170 LB)

1 STRUCTURAL CONTAINER
2 SINUSOIDAL SHAKER UNITS
1 RANDOM VIBRATION GENERATOR
1 MODULE-TO-STRUT ADAPTER

CRADLE ASSEMBLY (350 LB)

MAIN STRUCTURE
3 ATTACHMENT TRUNNIONS
1 DOCKING INTERFACE (ACTIVE)

2 LID RESTRAINT LATCHES
2 SHAKER MODULE RESTRAINT LATCHES
1 END ADAPTER RESTRAINT LATCH

MISCELLANEOUS (160 LB)

12 PIEZO-ELECTRIC ACCELEROMETERS
1 SIGNAL RELAY BOX
1 POWER & SIGNAL UMBILICAL
1 POWER AMP; 1 LOOP AMP; 1 TAPE RECORDER

TOTAL WEIGHT 795 LB

7.3 EXPERIMENT NO. 3 — CONSTRUCTION EQUIPMENT EFFECTIVENESS

The prime objective of Experiment No. 3 is to evaluate and demonstrate the relative effectiveness of specific items of equipment which are deemed necessary for space construction operations. Other test objectives are concerned with the installation of power/signal lines to the basic structure and installation of subsystem modules. The other tasks of this space construction systems study have shown the types of construction operation that should or could be performed, with a "cherry picker" mounted on the end of an extension arm (RMS). Figure 7-39 shows a typical operation wherein the cherry picker is a work platform for the EVA astronaut, allowing him to assist in pick-up of payloads, their installation with eye-level line of sight, and EVA astronaut performing small complex operations. Another piece of construction equipment is a holding and positioning aid (HAPA), which is used for the construction and servicing of most types of space platforms (Figure 7-40).

7.3.1 Configuration Description

Experiment No. 3 will investigate the feasibility of using several pieces of equipment in space construction operations and evaluate their effectiveness. Among those are the manned maneuvering unit (MMU), the orbiter remote manipulator system (RMS), and a payload holding and positioning aid. To assist in the evaluation, a deployable two-cell pentahedral structure, an equipment module with its own attachment adapter, and an electrical cable are included as part of the test hardware. This section describes the various elements of the Experiment No. 3, as illustrated in Figure 7-41, and their stowage within the orbiter cargo bay, deployment, and operation in space.

Manned Maneuvering Unit

The MMU is a self-contained propulsive backpack freeflyer which will allow crew members to apply their visual, mental, and manipulative capabilities beyond the orbiter cargo bay (References 7-6 and 7-7). The MMU is used in conjunction with the extravehicular mobility unit (EMU), a pressure suit, and life support system assembly which provides the astronaut with an EVA capability. The MMU attaches rigidly to the primary support system on the crew member's back. The astronaut, EMU, and MMU then form an integral system for EVA operations as seen in Figure 7-42.

The general configuration of the MMU is shown in Figure 7-43. It provides mounting brackets for ancillary equipment such as cameras, floodlights, drills, tools, instruments, etc., and power outlets for such equipment. It also features attachment provisions for carrying cargo or docking at a work station.

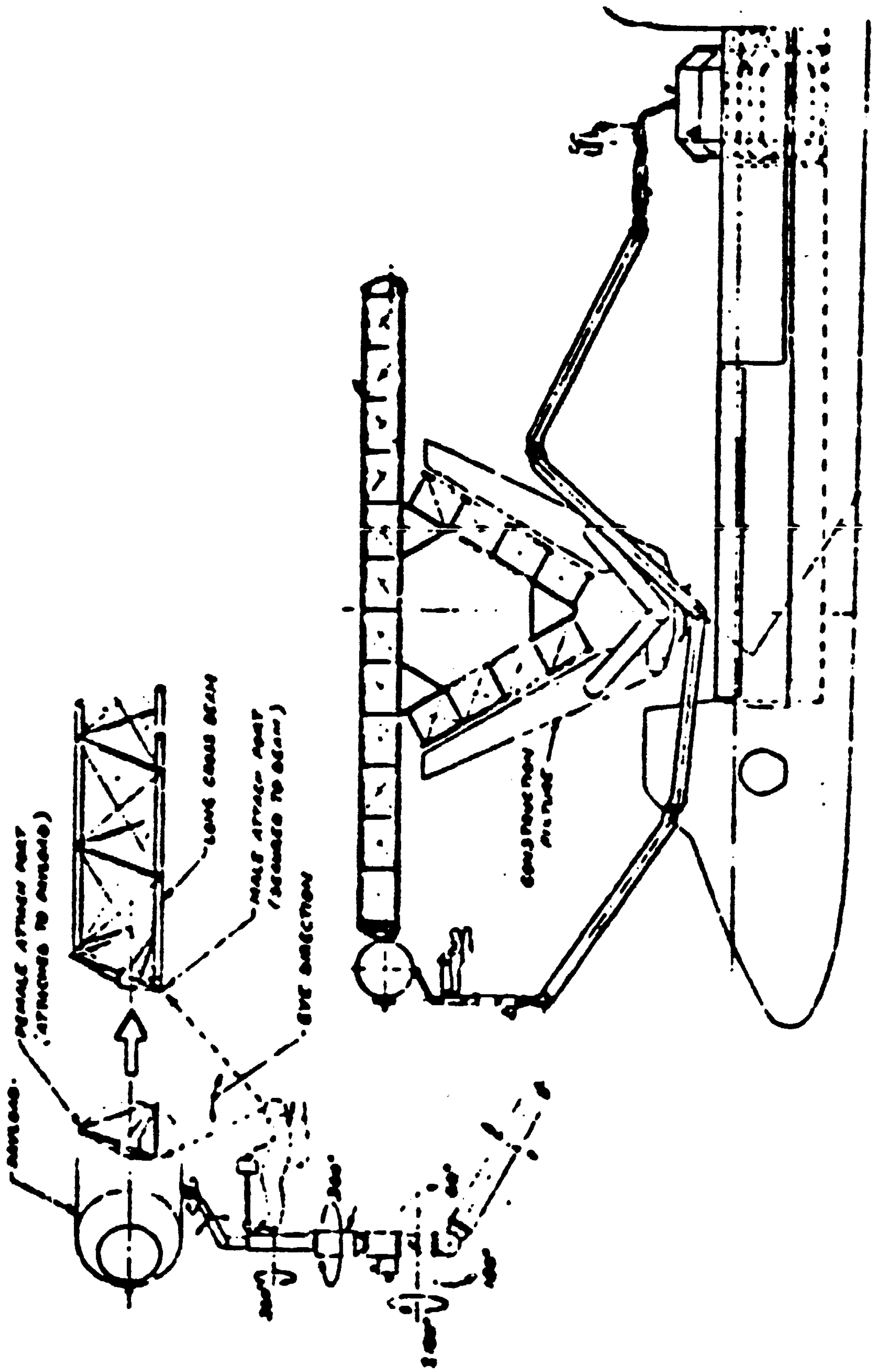


Figure 7-39. Cherry Picker and MMU Operations

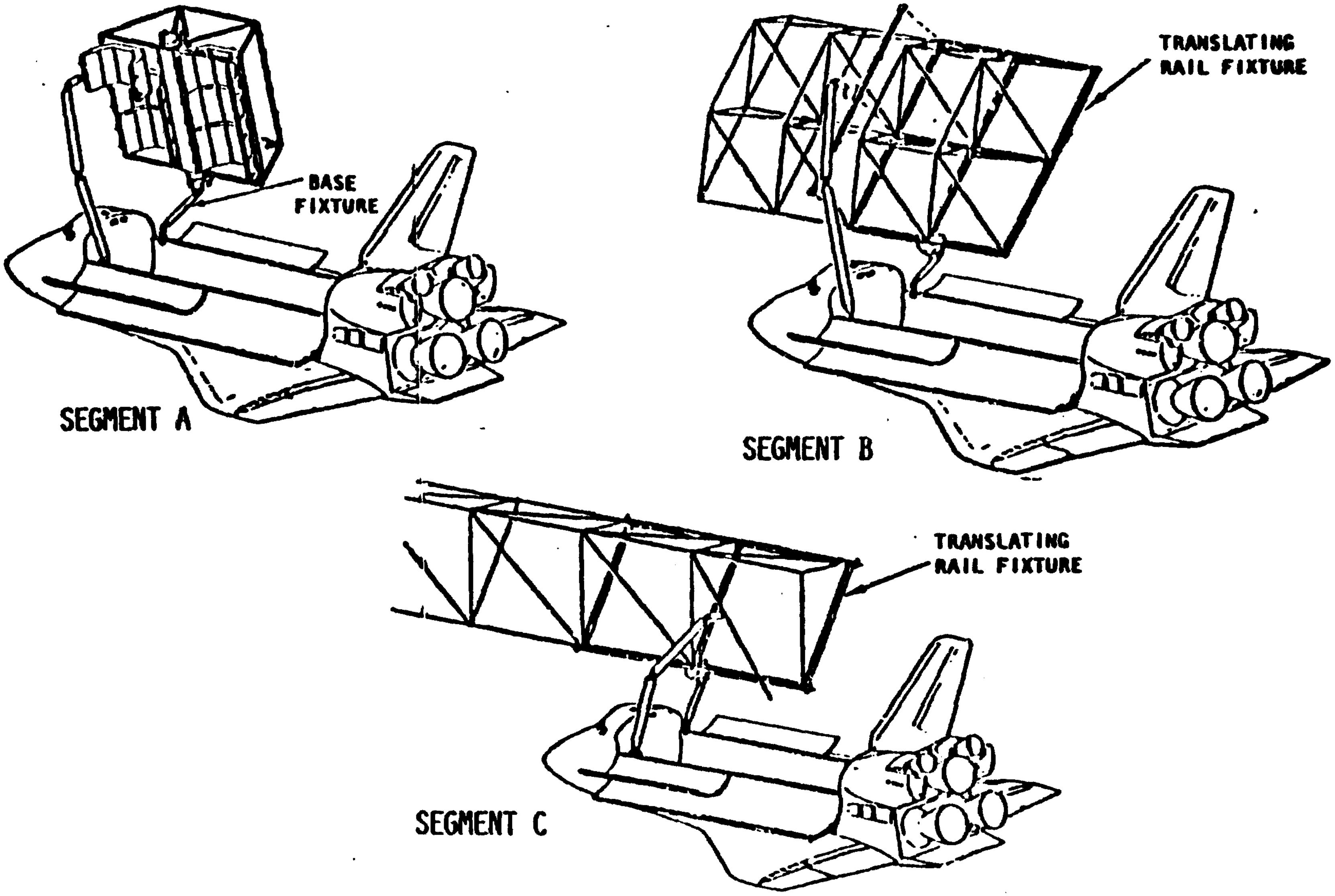


Figure 7-40. Construction Fixture Operations Phases

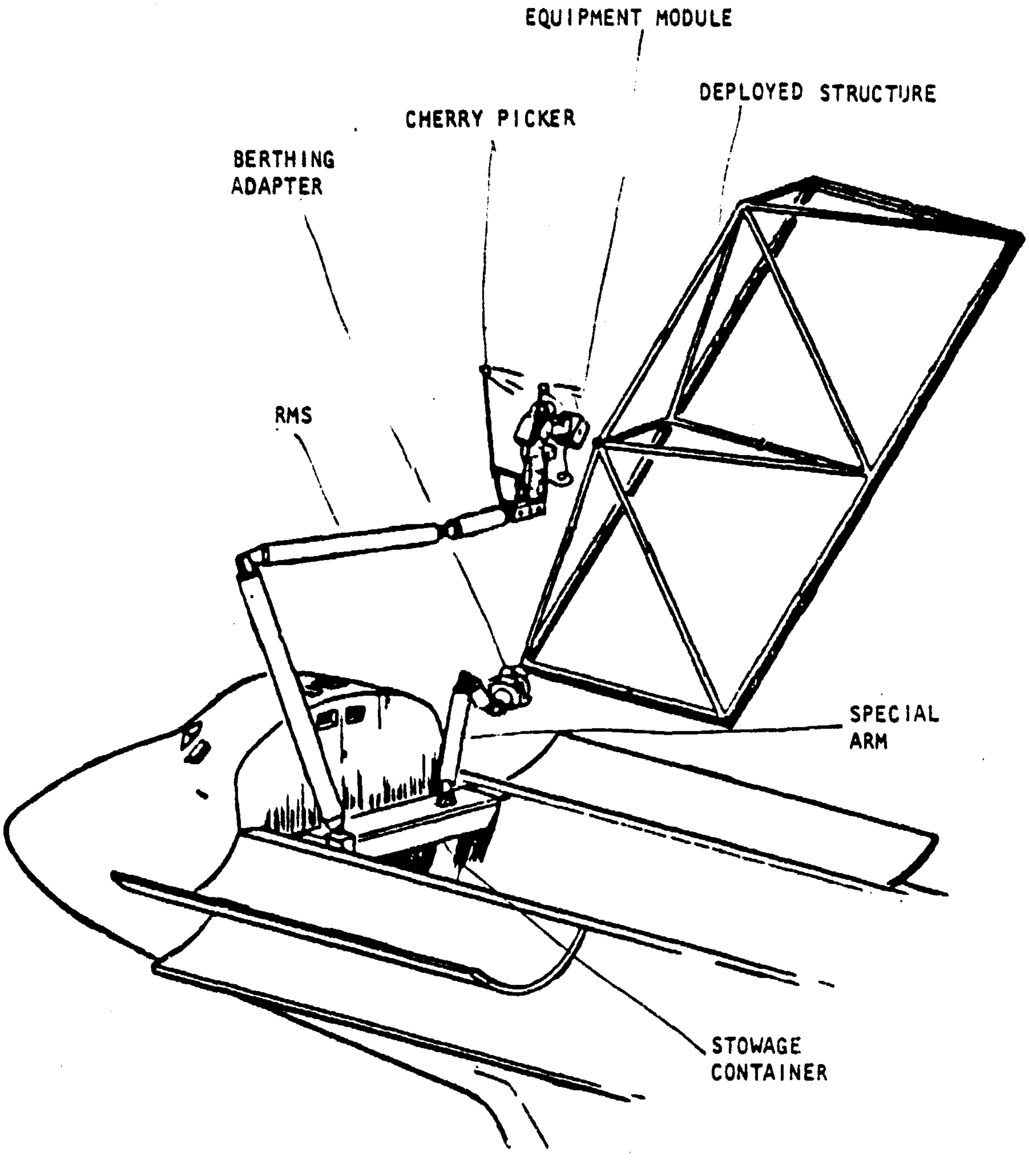


Figure 7-41. Experiment No. 3

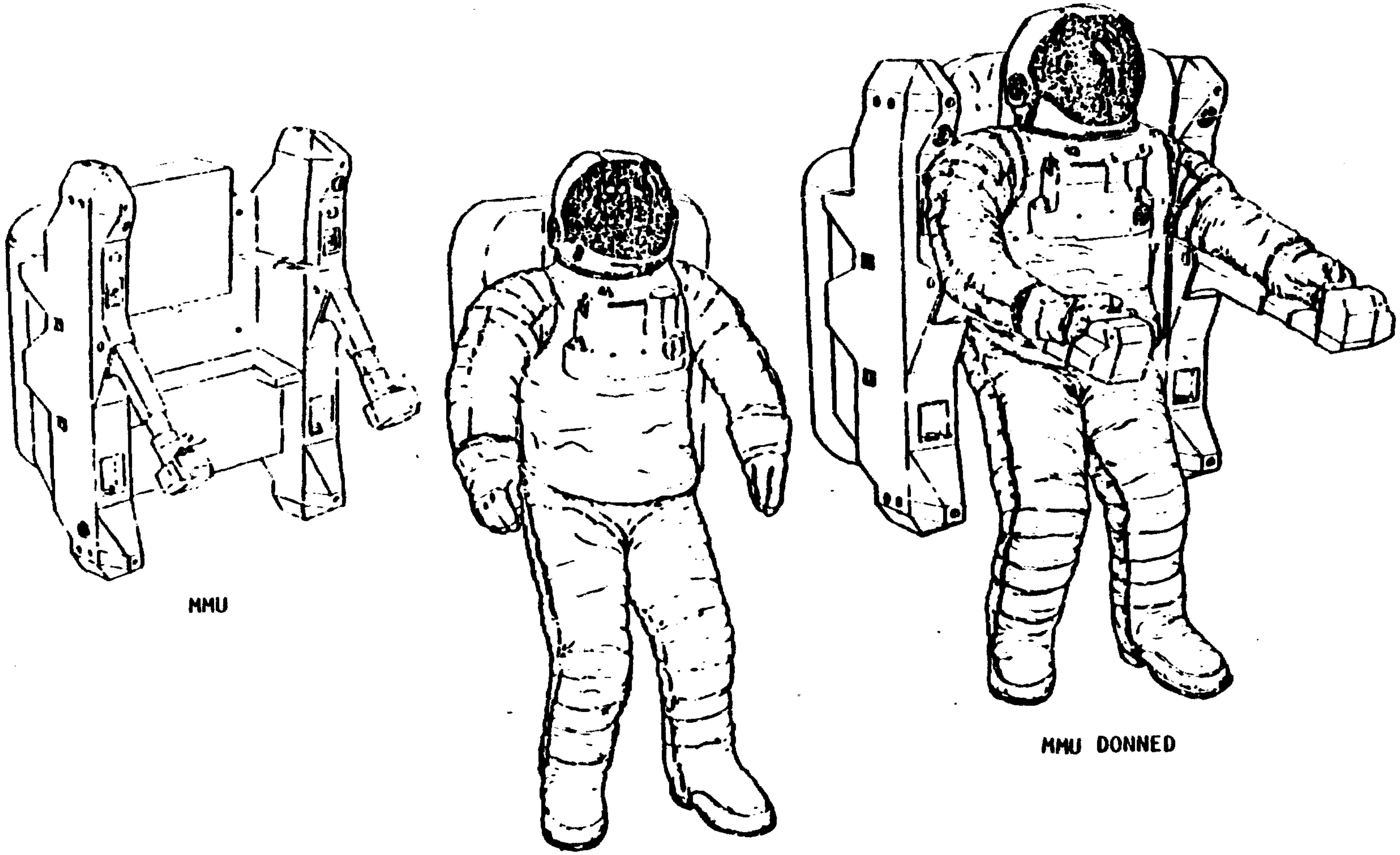


Figure 7-42. Space Shuttle Manned Maneuvering Unit (MMU)

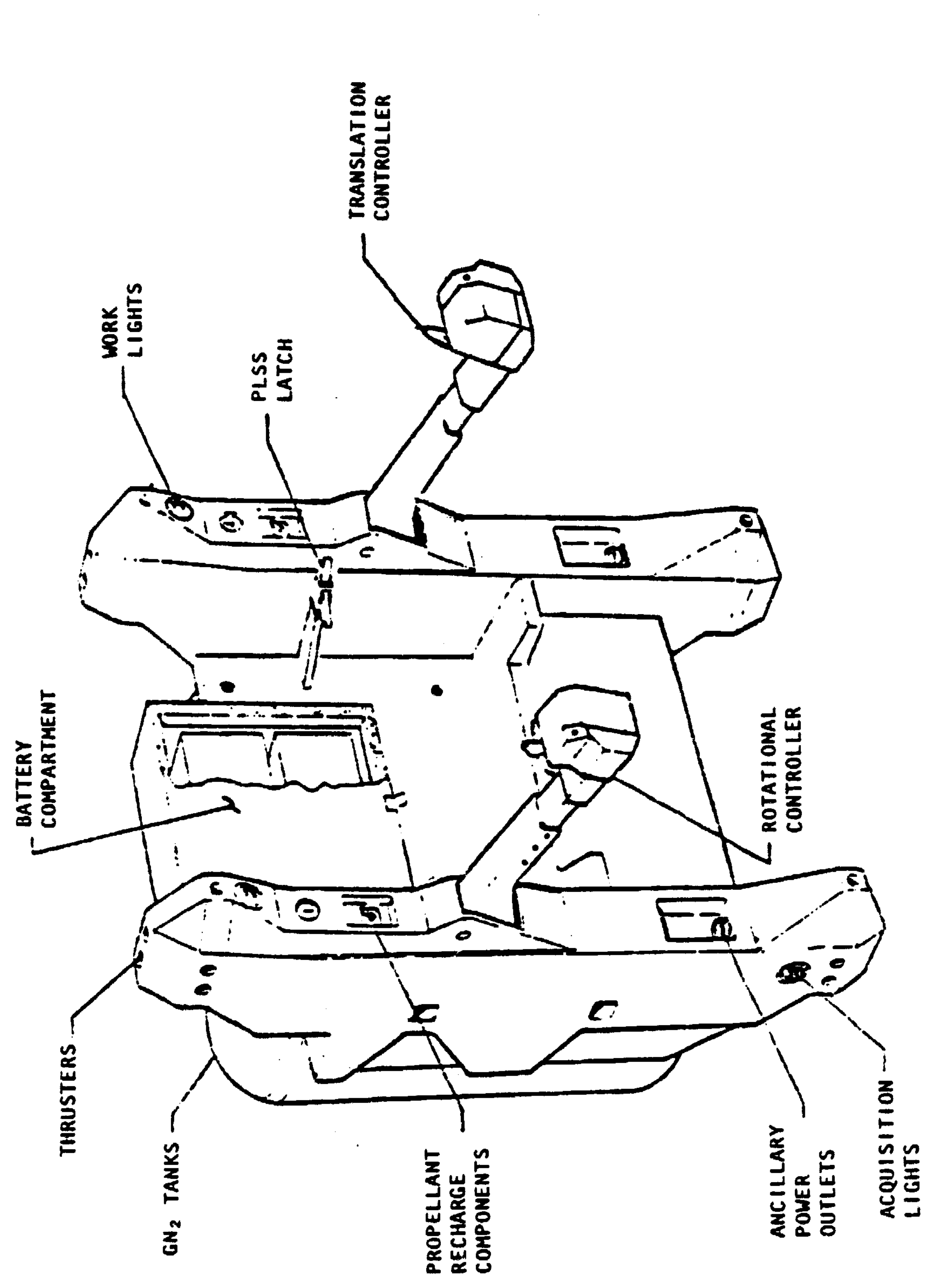


Figure 7-43. Manned Maneuvering Unit General Configuration

The MMU is stowed for launch and reentry in the flight support station (FSS) located in the orbiter cargo bay (Figure 7-44). The FSS structure provides environmental protection to the MMU during launch, on-orbit (non-operational) periods, reentry, and landing. The FSS also contains the necessary attachment provisions, foot restraints, and handholds for donning/doffing and servicing the MMU in orbit by an unassisted EVA astronaut. One FSS can be mounted on each side of the payload bay so two MMU's can be carried on each orbiter flight.

Cherry Picker

The cherry picker is a platform mounted at the end of the orbiter RMS and provides a means of conveniently transporting an EVA astronaut, tools, and mission hardware about the orbiter cargo bay. It is similar in application to terrestrial cherry pickers used by power utility companies. The cherry picker concept utilized in this study is shown in Figure 7-45. It is a Grumman concept (Reference 7-8), and among its planned functions are tasks associated with large space construction such as deployable fixtures, resupply fabrication machines, joining and aligning operations, and assembly and disassembly of structures. Its major elements include a base structure, a work platform, a stabilizer, a controls and displays console, light stanchion, a payload handling device, and equipment storage provisions. The cherry picker can be folded in a 7-step operation for stowage in the cargo bay. The folding sequence is illustrated in Figure 7-46.

Remote Manipulator System

As a standard part of the Shuttle payload deployment and retrieval system, the RMS (Figure 7-47) consists of control and monitoring devices, the manipulator arm, and a basic payload handling end effector (Reference 7-5). The manipulator is 15.24 m (50 ft) long and is mounted on the left side of the orbiter outside the payload envelope.

In Experiment No. 3, the RMS will assist in deploying and restowing of the structure, attach and detach an electrical cable from the structure, handle the cherry picker, and attach and detach an equipment module from the structure.

Holding and Positioning Aid (HAPA)

This fixture consists of a deployable arm and a berthing adapter which interfaces with the structure and holds it in the desired position and orientation. The Space Construction System Study has shown that the HAPA should have the capability of independent wrist action (Figure 7-48).

Some of the requirements and basic operation of the HAPA are similar to the operation of the NASA payload installation and deployment aid (PIDA), Figure 7-49. Therefore, an alternate design of the HAPA would be a modified PIDA which would retain all of the good features of the design wherever possible.

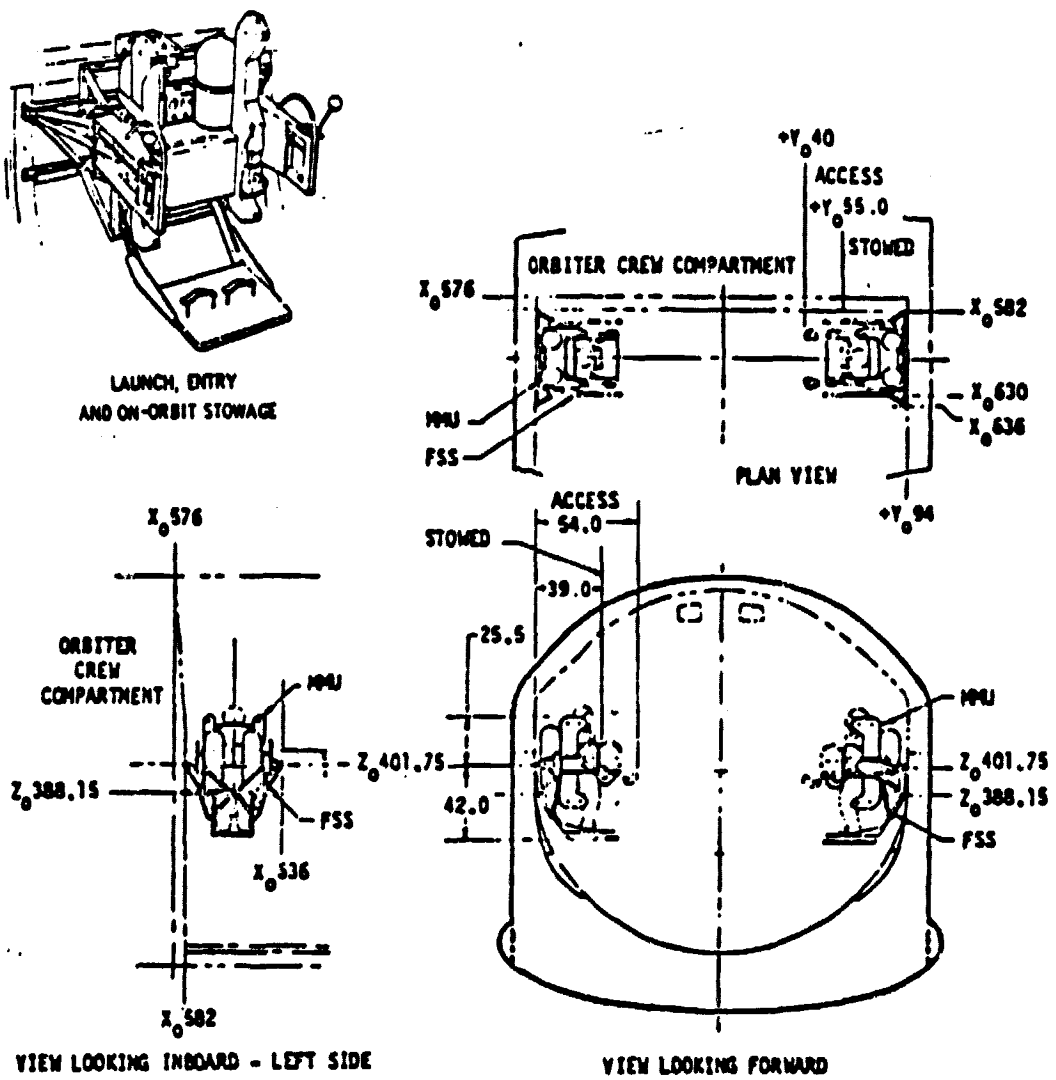


Figure 7-44. MMU Stowage Concept

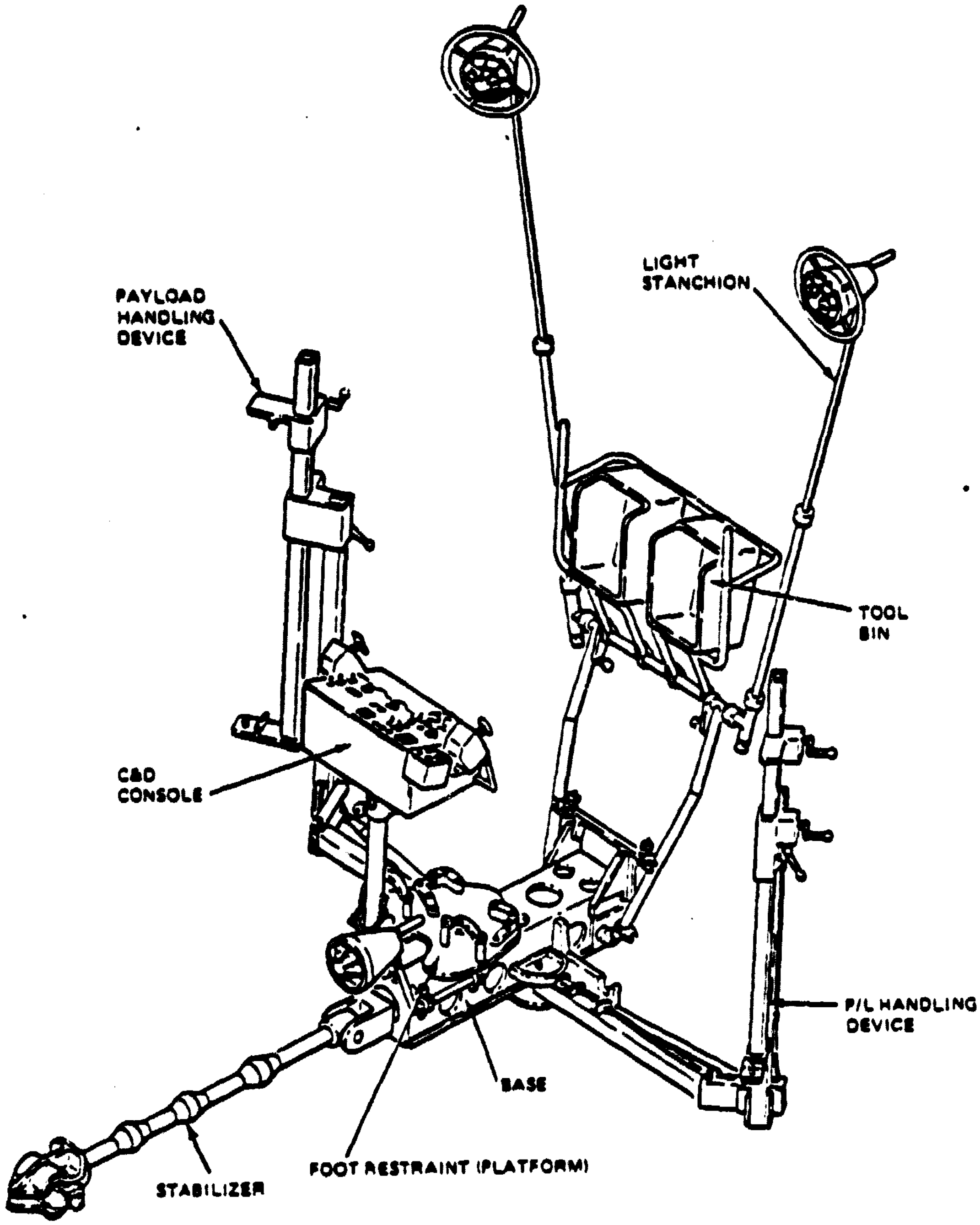


Figure 7-45. Cherry Picker General Configuration

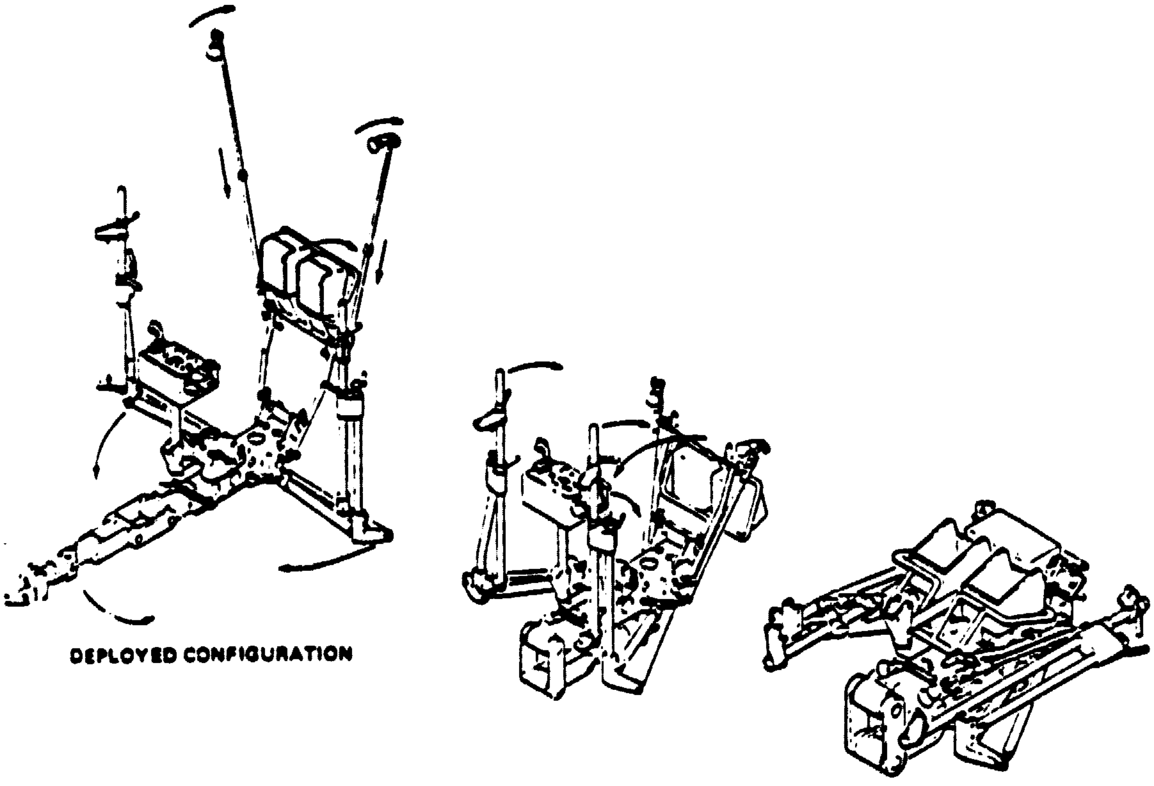


Figure 7-46. Cherry Picker Folding Sequence

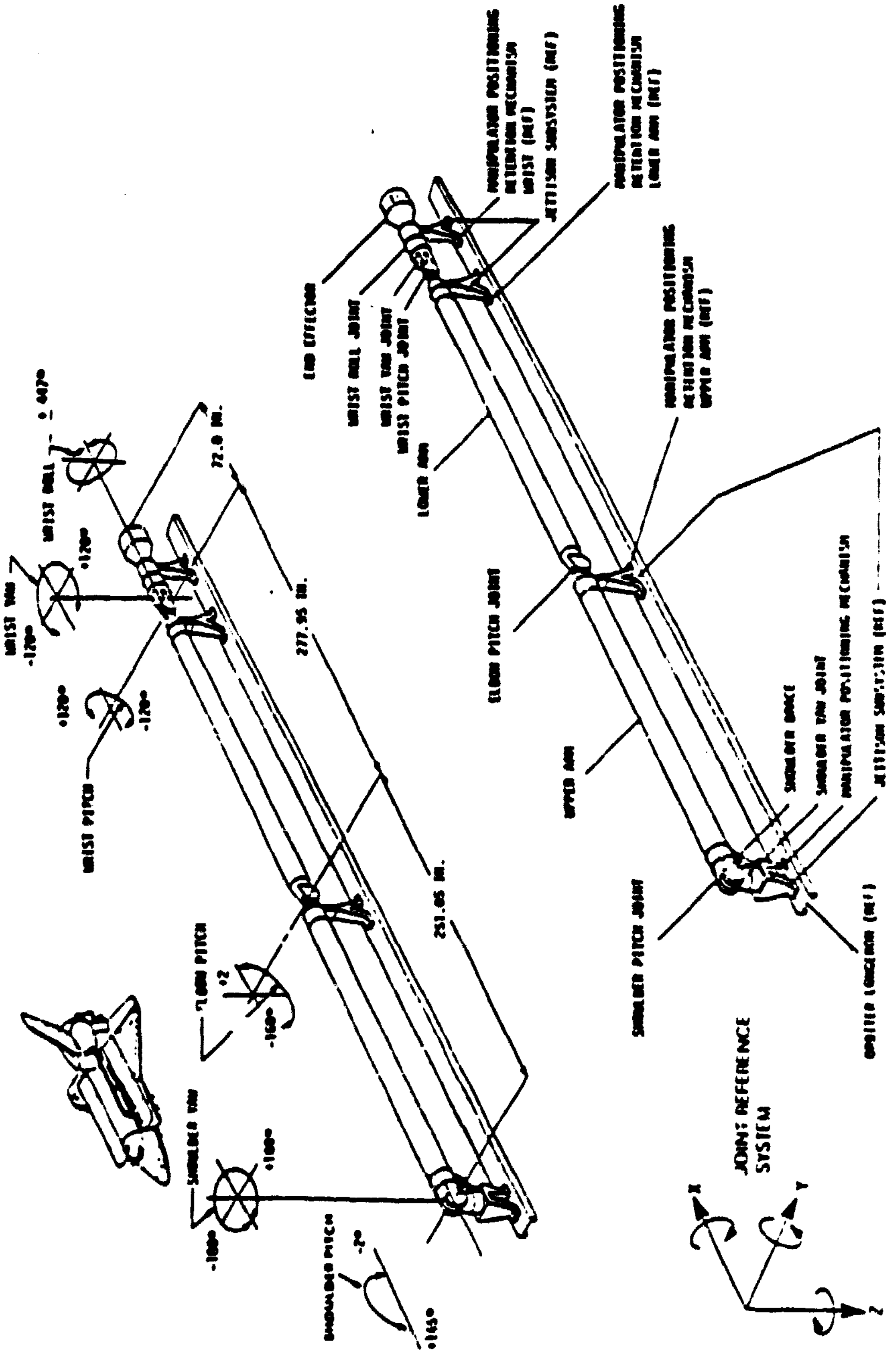


Figure 7-47. Remote Manipulator System

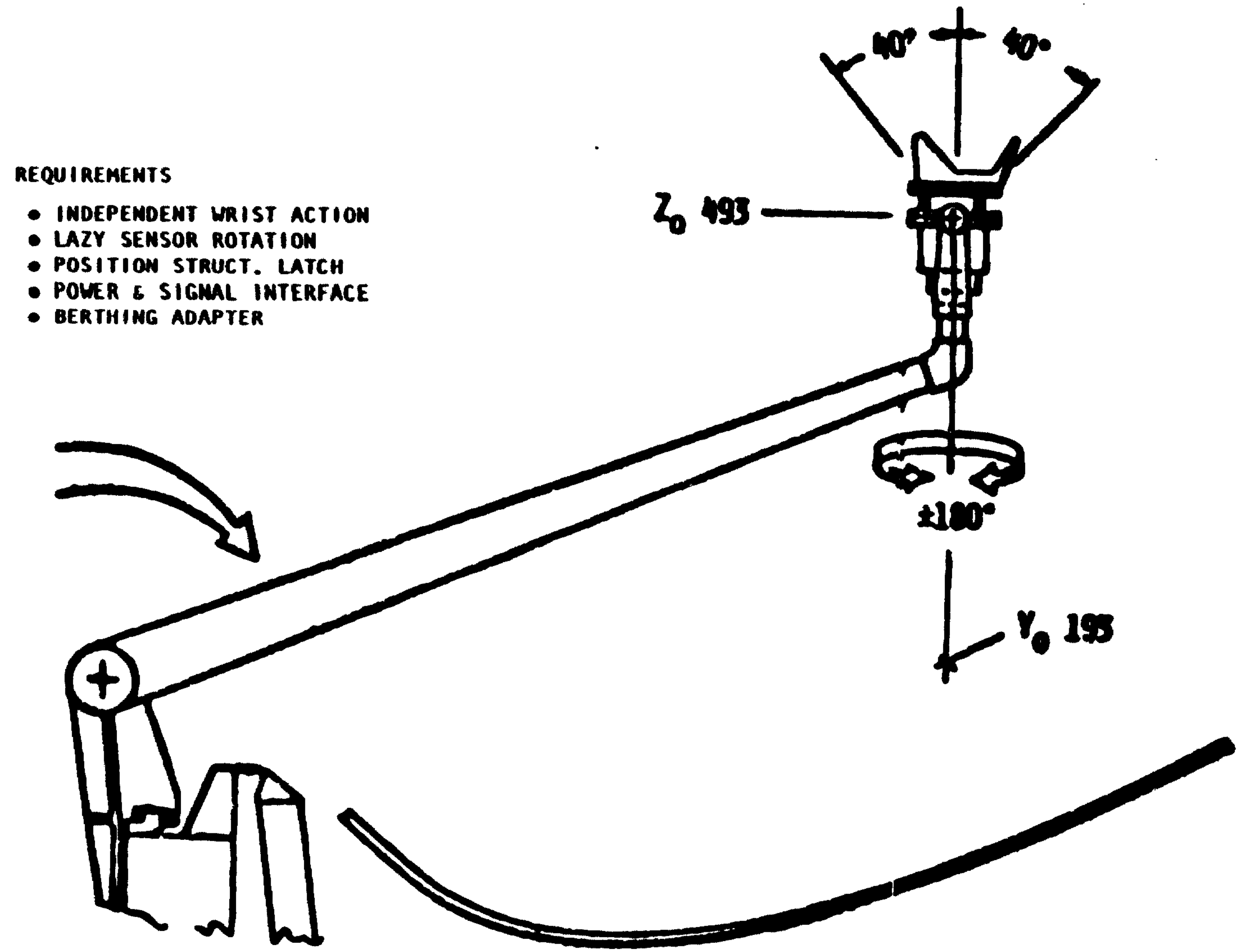


Figure 7-48. Holding and Positioning Aid -- General Arrangement

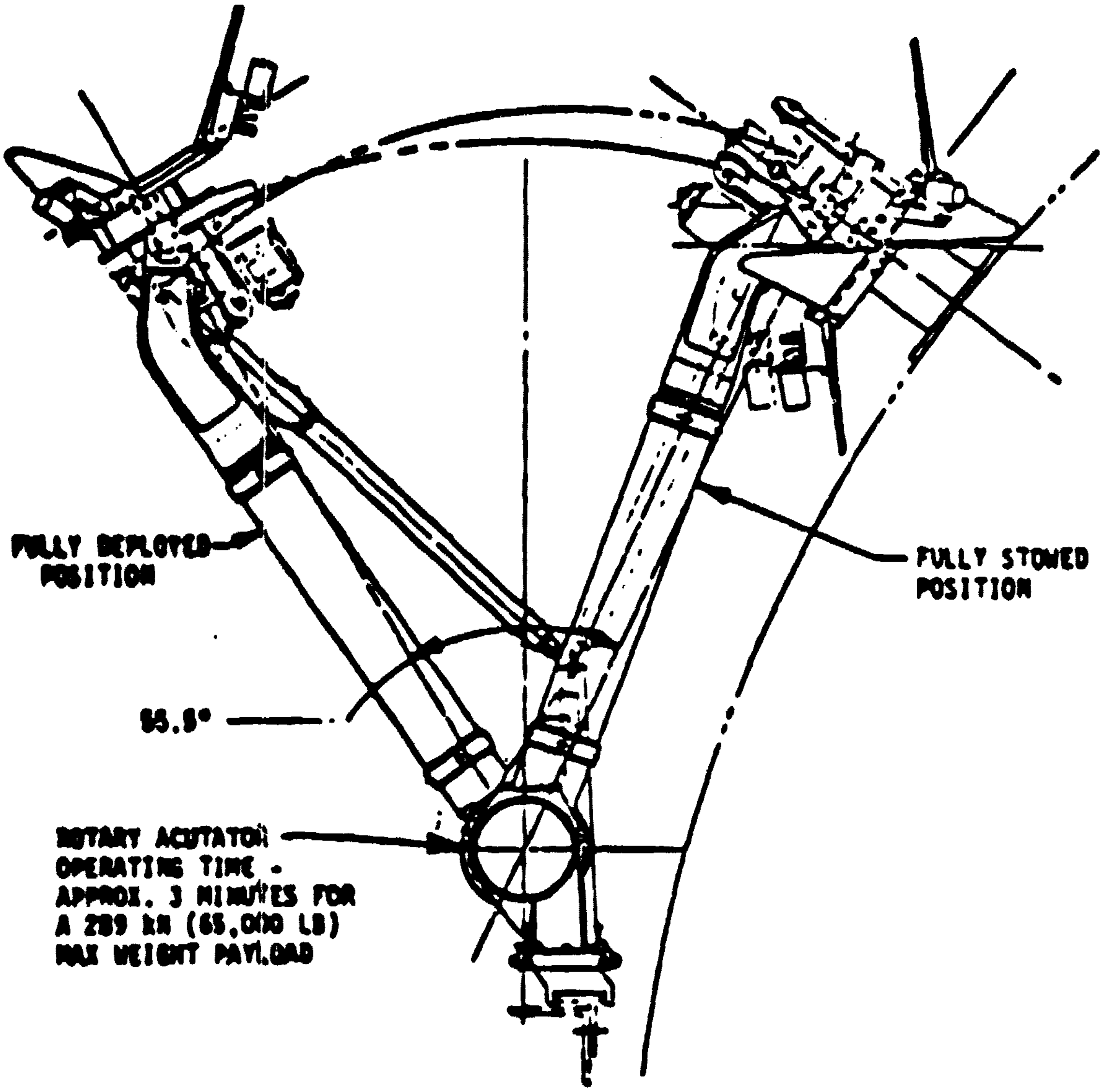


Figure 7-49. Current PIDA Configuration

The modifications would consist of the following:

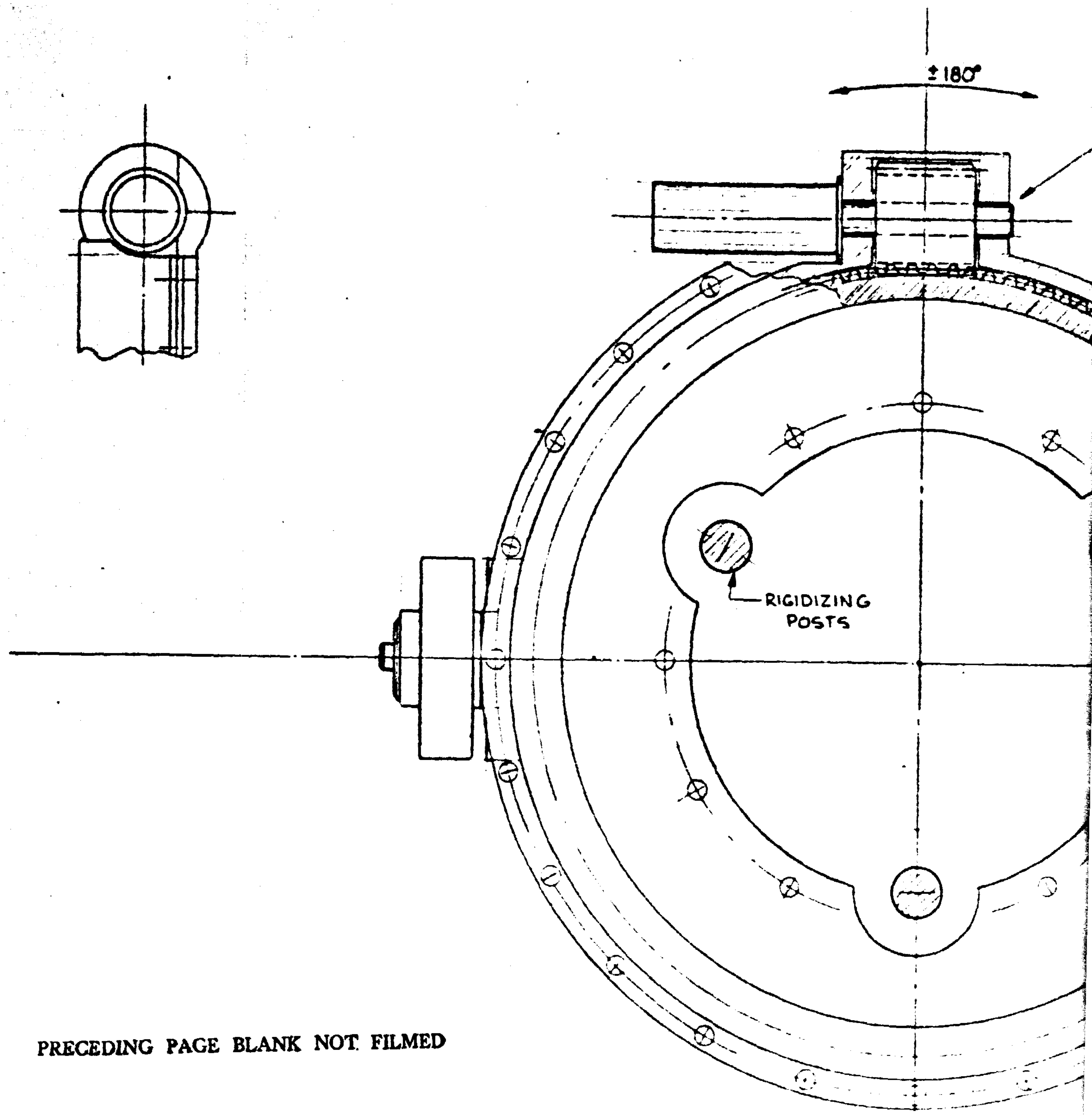
- Elimination of the drag link which controls the motion of the docking mechanism and the substitution of a ±40° rotation about the trunnion
- Addition of a motorized drive capable of ±180° axial rotation of the docking mechanism
- Addition of electrical interconne... across the payload/PIDA interface
- Addition of a method of preloading across the payload/PIDA interface to take out backlash
- An increase in length of the mounting boom and a stronger attachment to the orbiter.

Functional concepts for these design modifications have been detailed on Drawing No. 42537-100, Figure 7-50, which shows on Sheet 2, Zone 4 the modified PIDA (MPIDA) installed on the orbiter. Only a single PIDA arm is required for the HAPA operation, but the structural interface must be capable of withstanding offset moments and torques imposed by the work activities on the structure the HAPA is holding.

Figure 7-50, Sheet 2, Zones 9 through 18, shows the electrical interconnects and preloading across the MPIDA/payload interface. An electric gear head motor drives a wormwheel which has an integral internal spur gear. The internal spur gear rotates three equally spaced gears which are threaded internally to form nuts. Each gear/nut drives a plunger which performs two functions — (1) acts as an electric connecter; and (2) preloads across the MPIDA/payload interface.

The three plungers form three separate electric connections, which can be designated System A, System B, and a spare. The number and size of the wires through each plunger is TBD. The outside diameter of the plunger enters the receptacle before the electric pins engage, and forms a positive guide and alignment. The plunger is prevented from rotating by a keyed bushing.

A requirement exists for eliminating backlash between the MPIDA and payload interfaces after they are captured. With a current PIDA, a certain amount of backlash must exist to allow the capture latches to function. To achieve this elimination of backlash, each plunger has a shoulder machined into its outside diameter. As the plunger advances, the sequence of events is as follows:



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SECTION A-A

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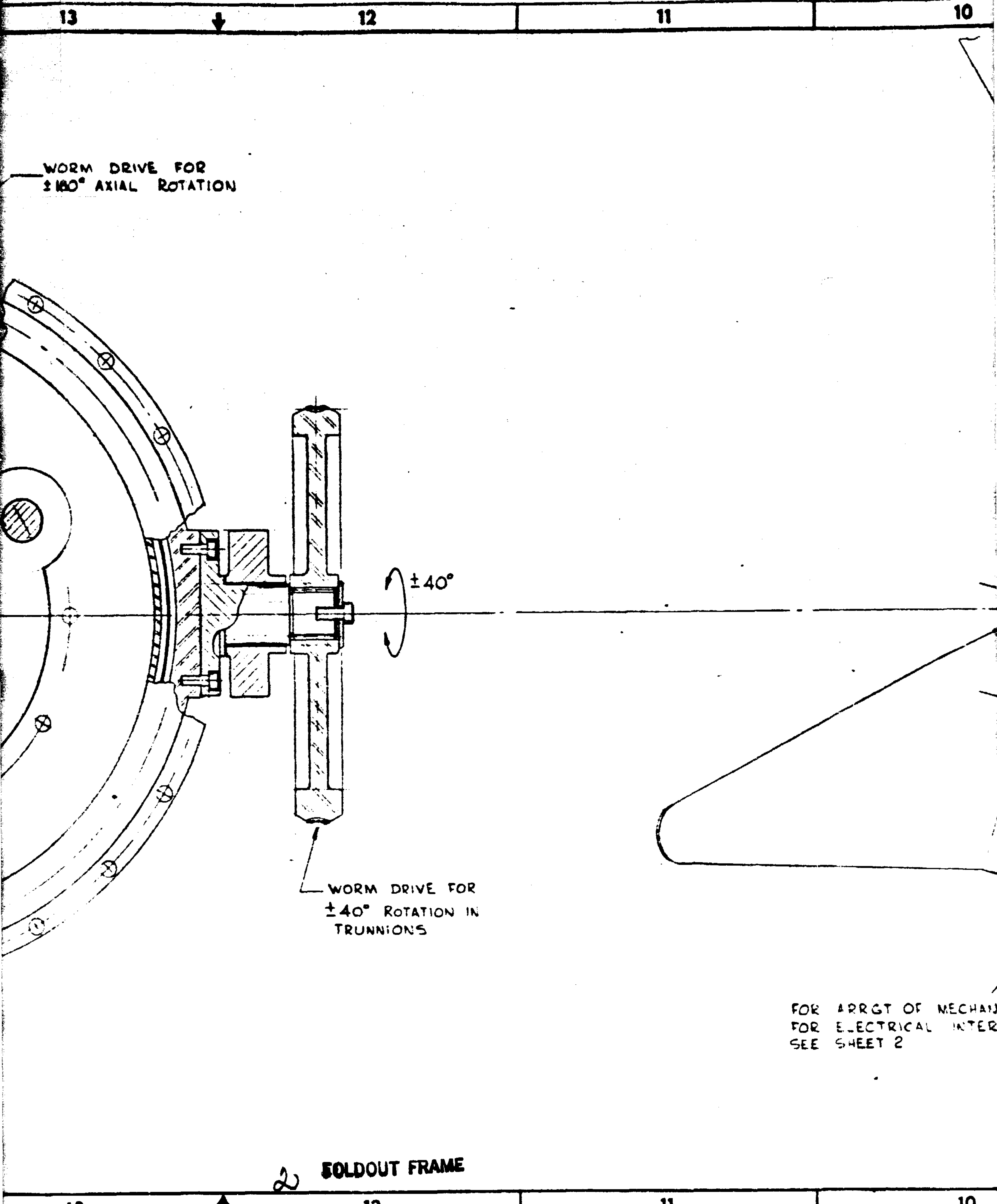
13
12
11
10
WORM DRIVE FOR
±180° AXIAL ROTATION
±40°
WORM DRIVE FOR
±40° ROTATION IN
TRUNNIONS
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FOR ELECTRICAL INTER
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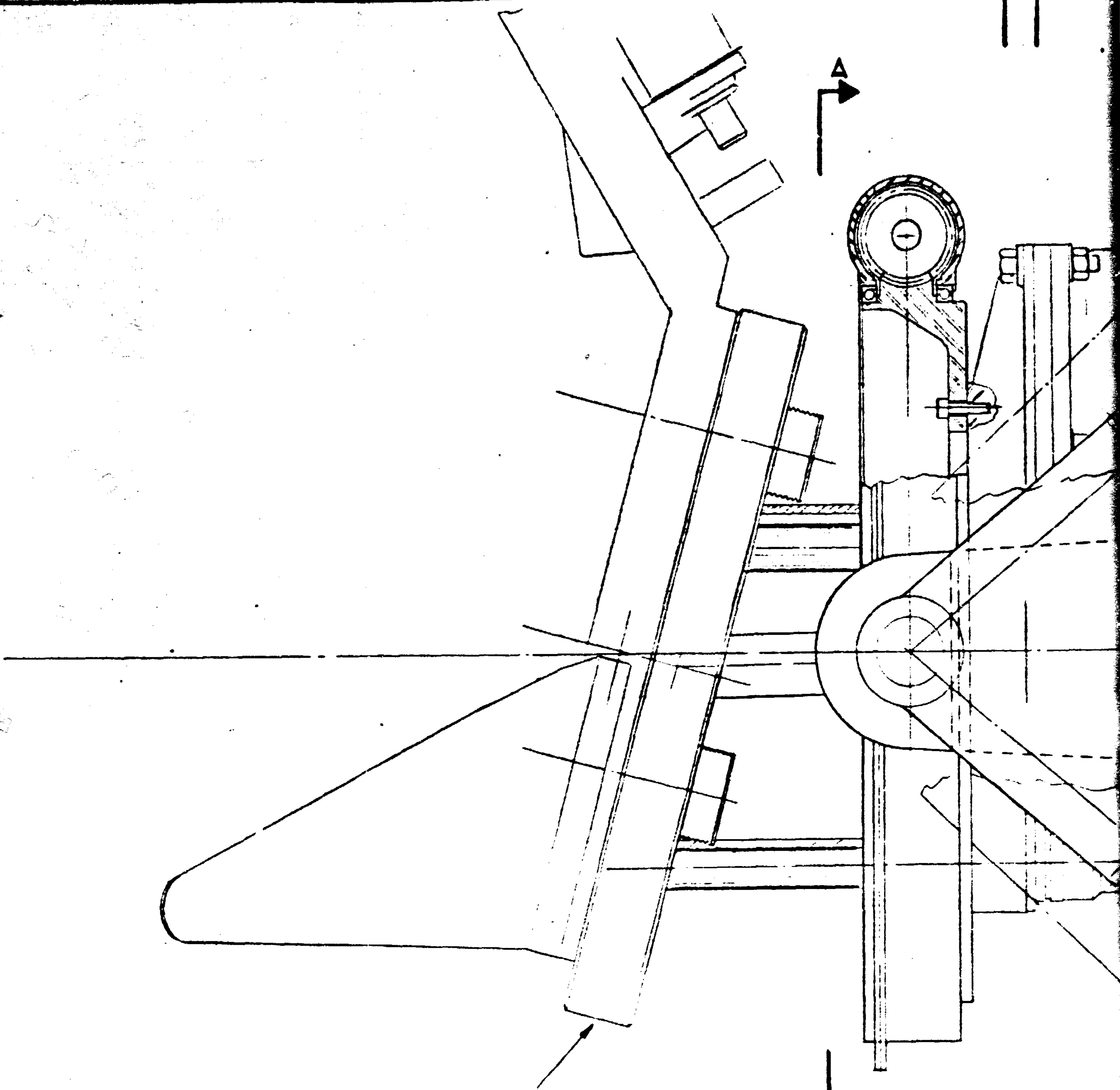
11	10	9



FOR ARRGT OF MECHANISM
FOR ELECTRICAL INTERCONNECTS
SEE SHEET 2

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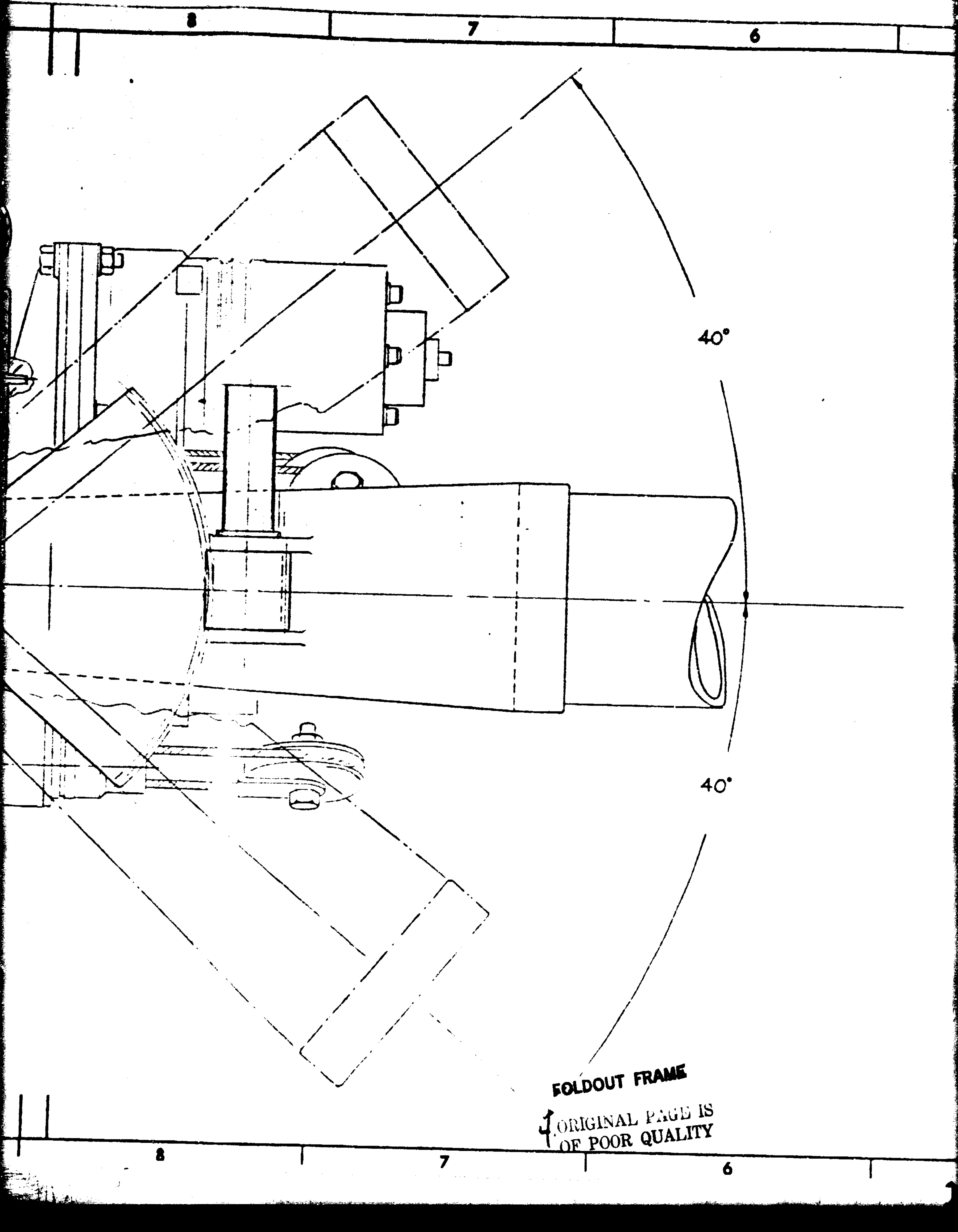

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ZONE	LTR	REVISIONS DESCRIPTION	DATE	APPROVED

THIS DESIGN IS A MODIFICATION OF THE NASA PAYLOAD INSTALLATION & DEPLOYMENT AID (PIDA) DWG SED-36117500 12-6-78.

THE MODIFICATIONS CONSIST OF;

1. ELIMINATION OF THE DRAG LINK & SUBSTITUTION OF A ±40° INDEPENDENT CAPABILITY OF TRUNNION DRIVE.
2. ADDITION OF A ±180° AXIAL ROTATION CAPABILITY OF THE PIDA DOCKING MECHANISM.
3. ADDITION OF ELECTRICAL INTERCONNECTS ACROSS THE PIDA/PAYLOAD INTERFACE.
4. ADDITION OF A MECHANISM TO PRELOAD THE PIDA/PAYLOAD INTERFACE.
5. INCREASE IN LENGTH OF THE MOUNTING BOOM.

Figure 7-50.

DR BY: R J HART, FEB 80	Rockwell International Corporation, Space Division
CHK BY:	SEGMENT A CONSTRUCTION FIXTURE
APPROVED BY	MODIFIED PIDA
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42537-100

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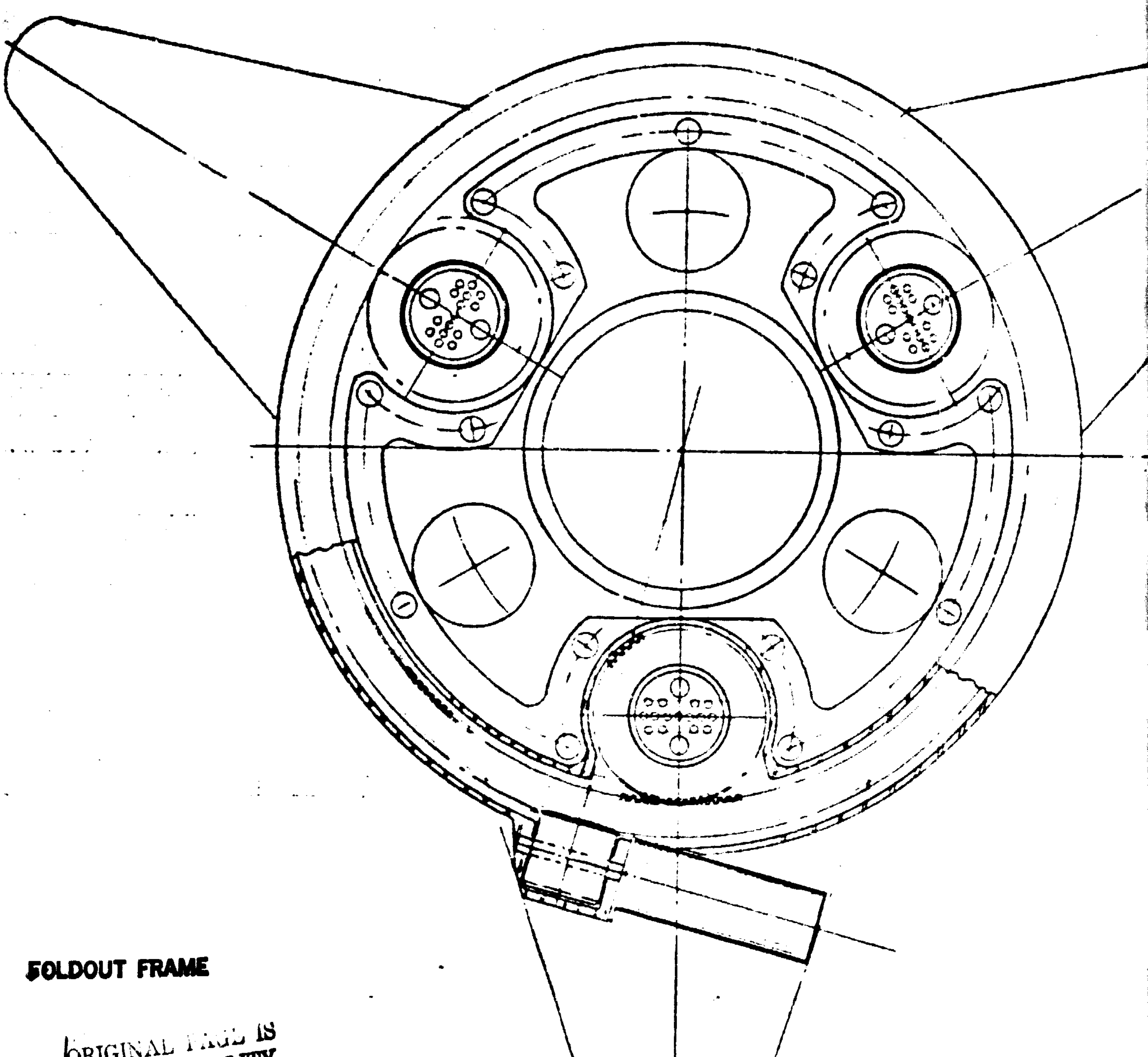

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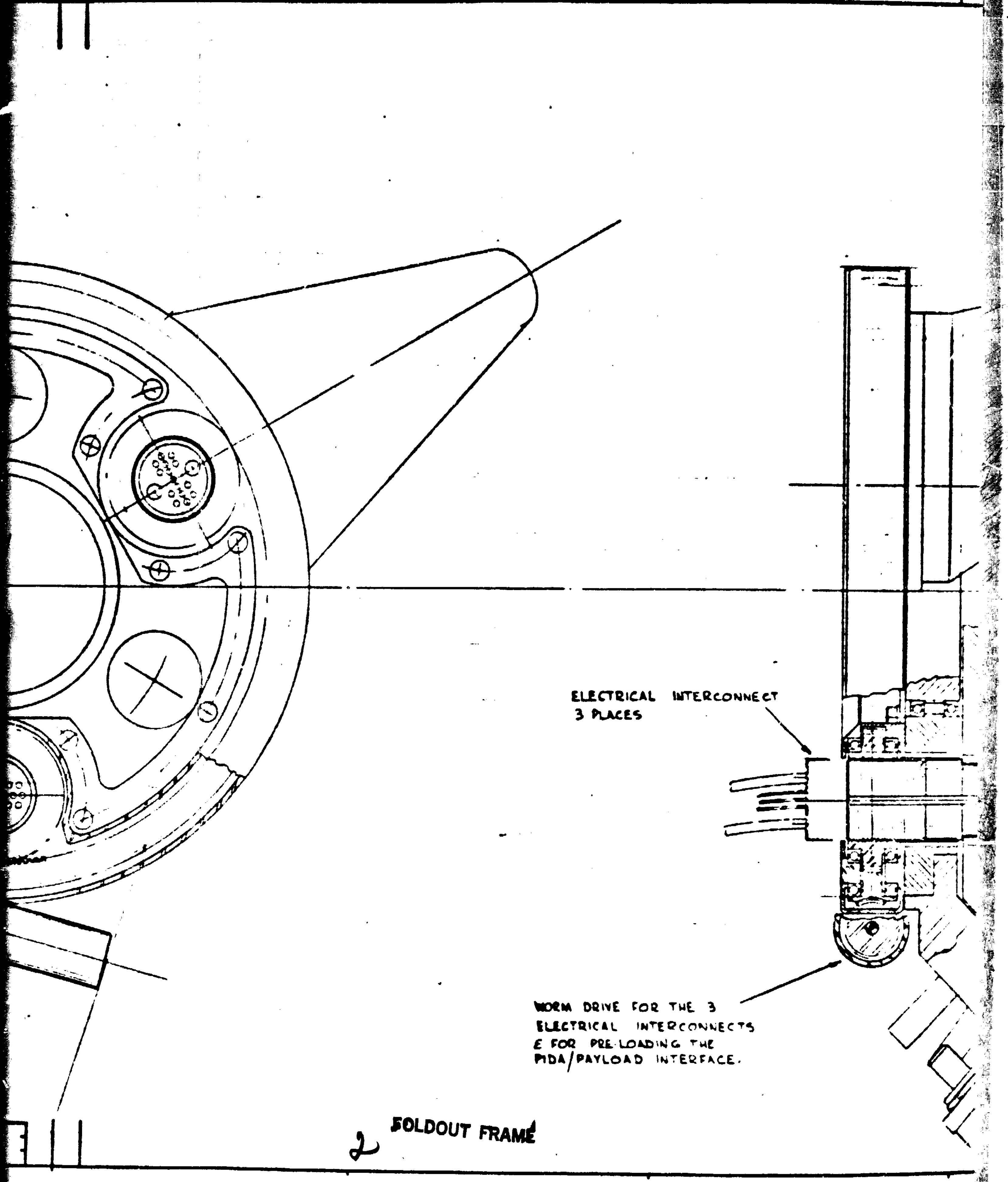

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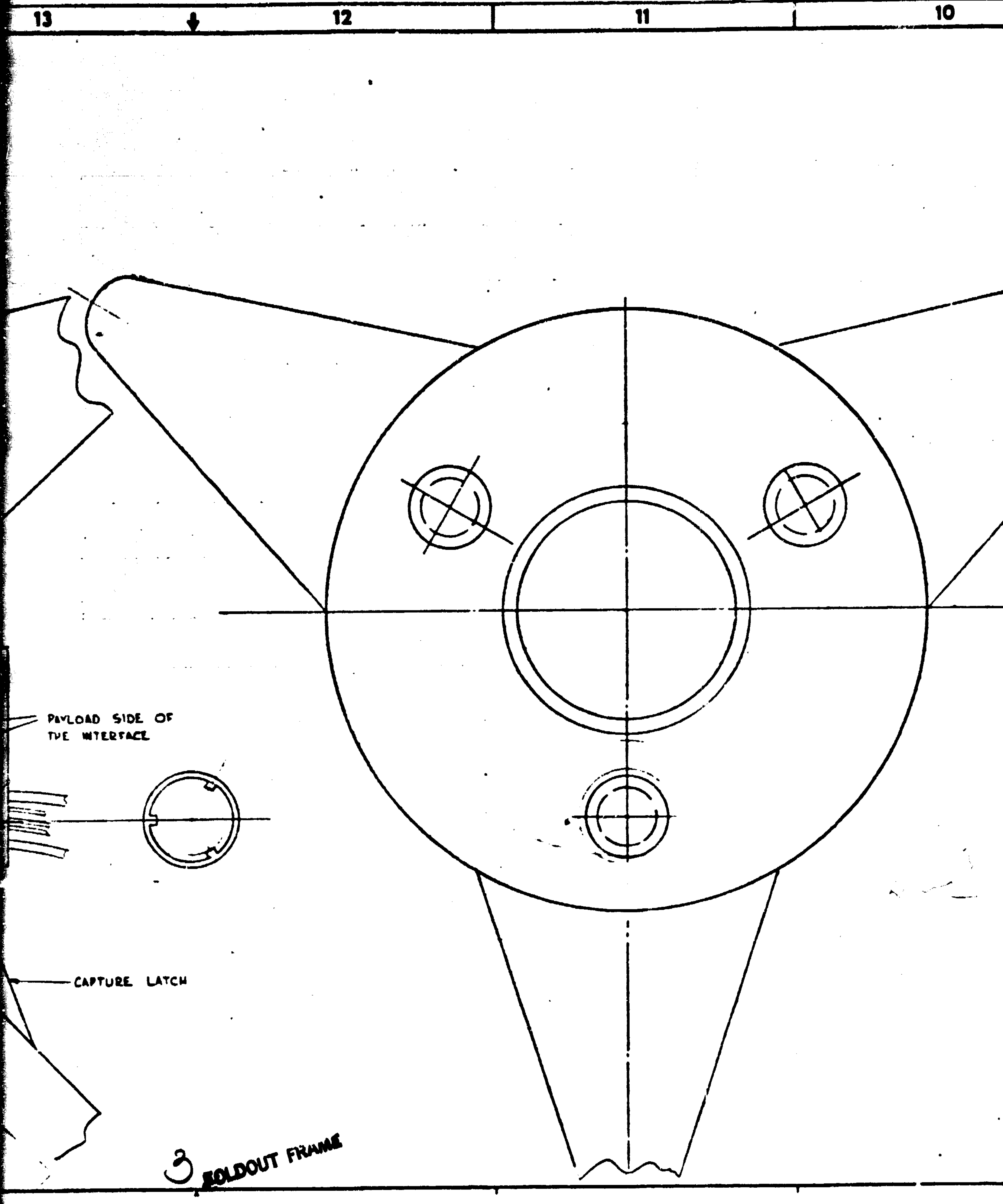

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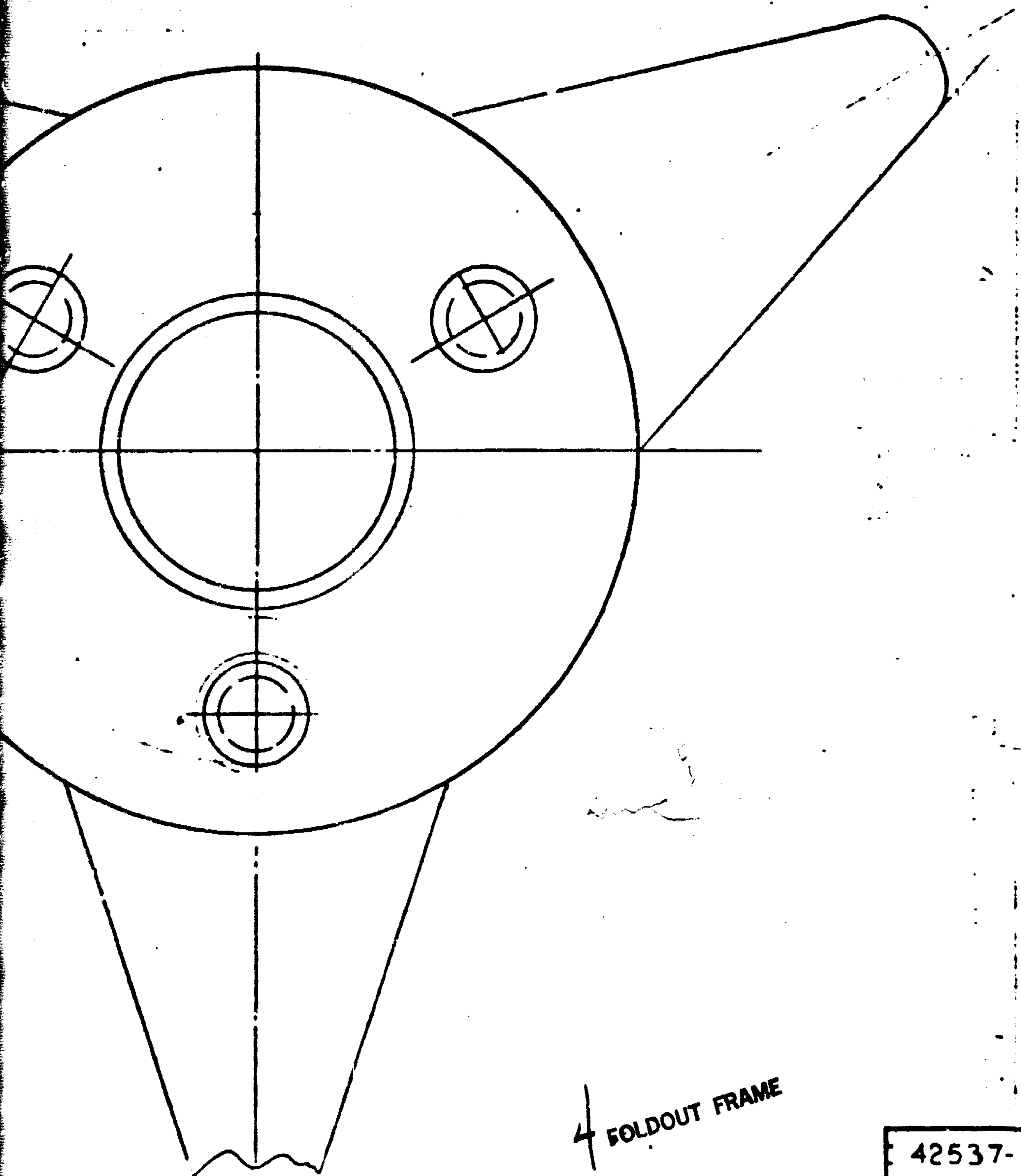
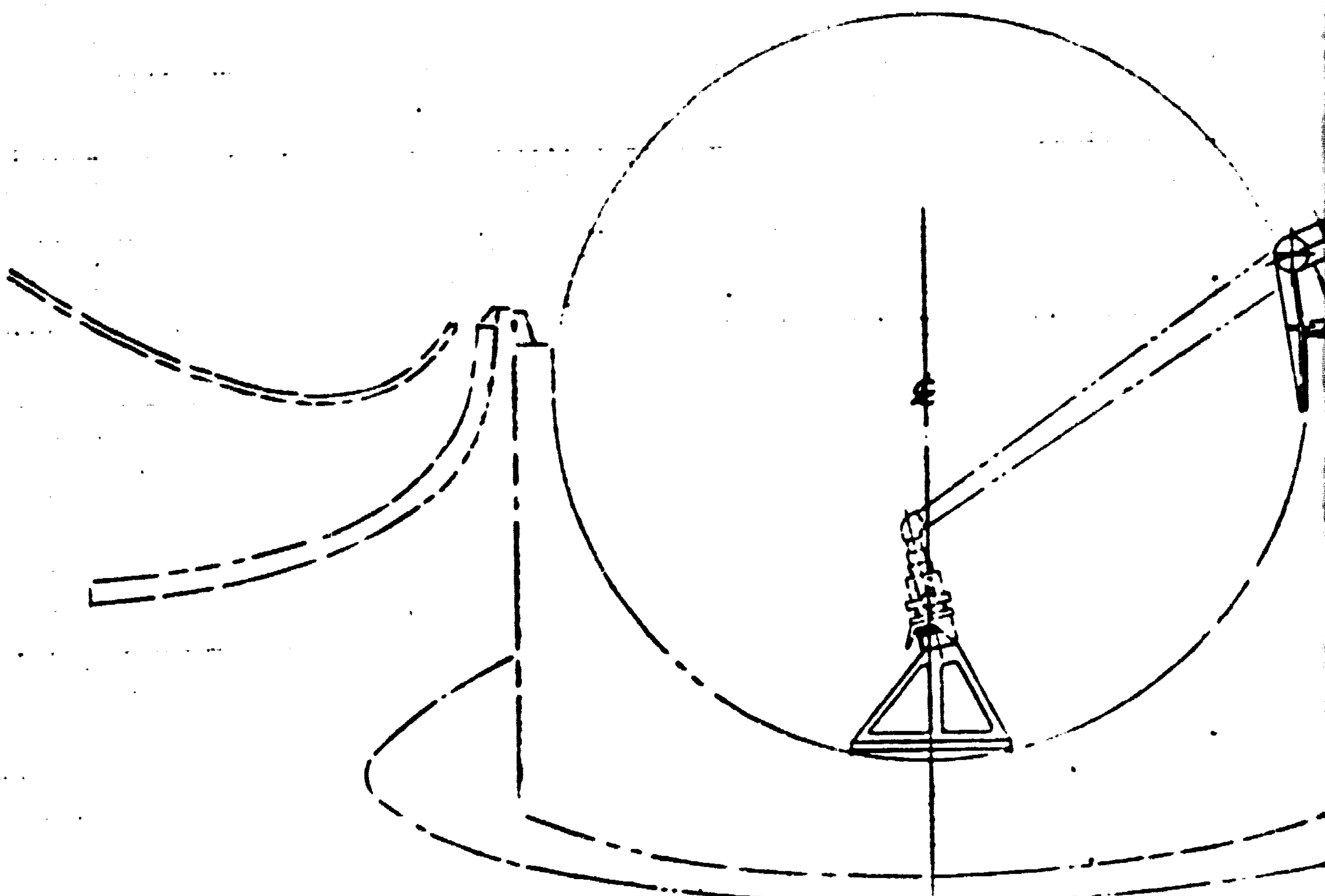
11

10



4 FOLDOUT FRAME

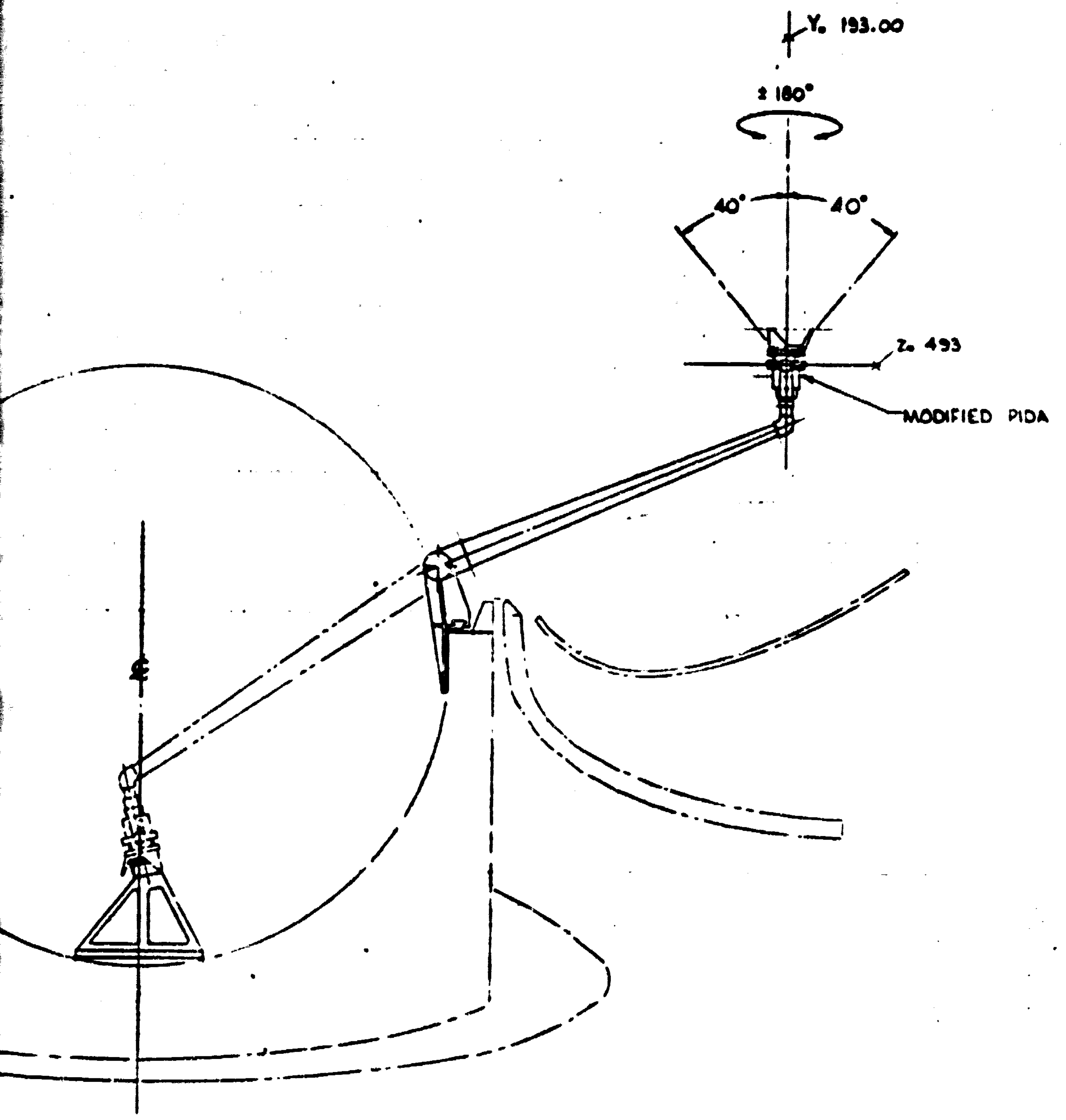
42537-100 SH 2



VIEW LOOKING FWD

SCALE 1/20

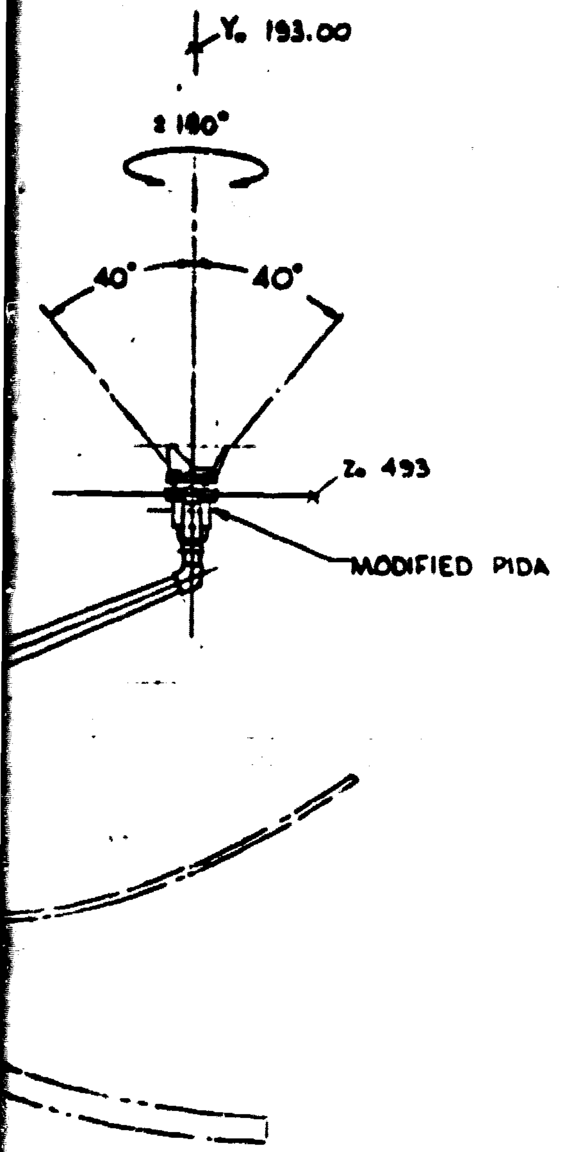
5 FOLDOUT FRAME



VIEW LOOKING FWD

SCALE 1/20

6 FOLDOUT FRAME



REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPROVED

42537-100

Figure 7-50

DR BY R.J. HART FEB 80	
CHK BY	
APPROVED BY	SEGMENT 'A' CONSTRUCTION FIXTURE MODIFIED PIDA
SIZE L	CODE IDENT NO 03953 · DRAWING NO 42537-100
SCALE	SHEET 2 of 2

FOLDOUT FRAME 6

FOLDOUT FRAME 7

- The outside diameter of the plunger enters the receptacle and forms a positive alignment of the MPIDA/payload.
- The electric pins begin to engage.
- The shoulder on the outside diameter of the plunger bears against the payload interface and pushes it back against the capture latches.

It is necessary that the payload side of the interface be equipped with a spring device in order to achieve the desired preload without the danger of overloading.

Figure 7-50 (Sheet 1) shows the mechanisms for the ±40-degree trunnion rotation and for the ±180-degree axial rotation.

The 40° trunnion rotation is generated by a gear head motor mounted on the yoke which forms the end of the mounting boom. The motor drives a worm and an 80° sector of a work wheel which is splined directly to the trunnion. The worm drive will effectively resist the application of loads which tend to backdrive.

The trunnions are attached to a ring which fits between the arms of the yoke. The ring moves ±40° with the trunnions. A motorized worm drive on the ring is used to rotate the worm wheel which is attached to the docking mechanism through the desired range of ±180°.

The basic design of the docking mechanism of the PIDA remains unchanged. The attenuator, the cable drive, the capture latches, and the push rods of the PIDA are used in the MPIDA.

The MPIDA is to be designed to withstand a force of 15 pounds imposed by the RMS at a distance of 50 feet (750 ft/lb). The preload across the MPIDA/payload interface is approximately 1500 pounds at each of the three plungers.

Figure 7-51 shows the electric cable across the ±40° and the ±180° rotations. The cable passes through the center of the mounting boom, around a take-up reel, and then to the MPIDA docking head.

Pentahedral Structure

To assist in the evaluation of the construction equipment, a deployable 2-cell pentahedral structure is included in the experiment. The structure consists of eight rigid columns 3.94 m (12.94 ft) long, eight hinged columns 3.94 m (12.94 ft) long, two hinged diagonal columns 5.64 m (18.49 ft) long, six base union assemblies, two apex union assemblies, an equipment module with its own attachment adapter, and a passive berthing adapter attached to one of the base unions. The general arrangement of the structure in the deployed and folded positions is shown in Figure 7-52.

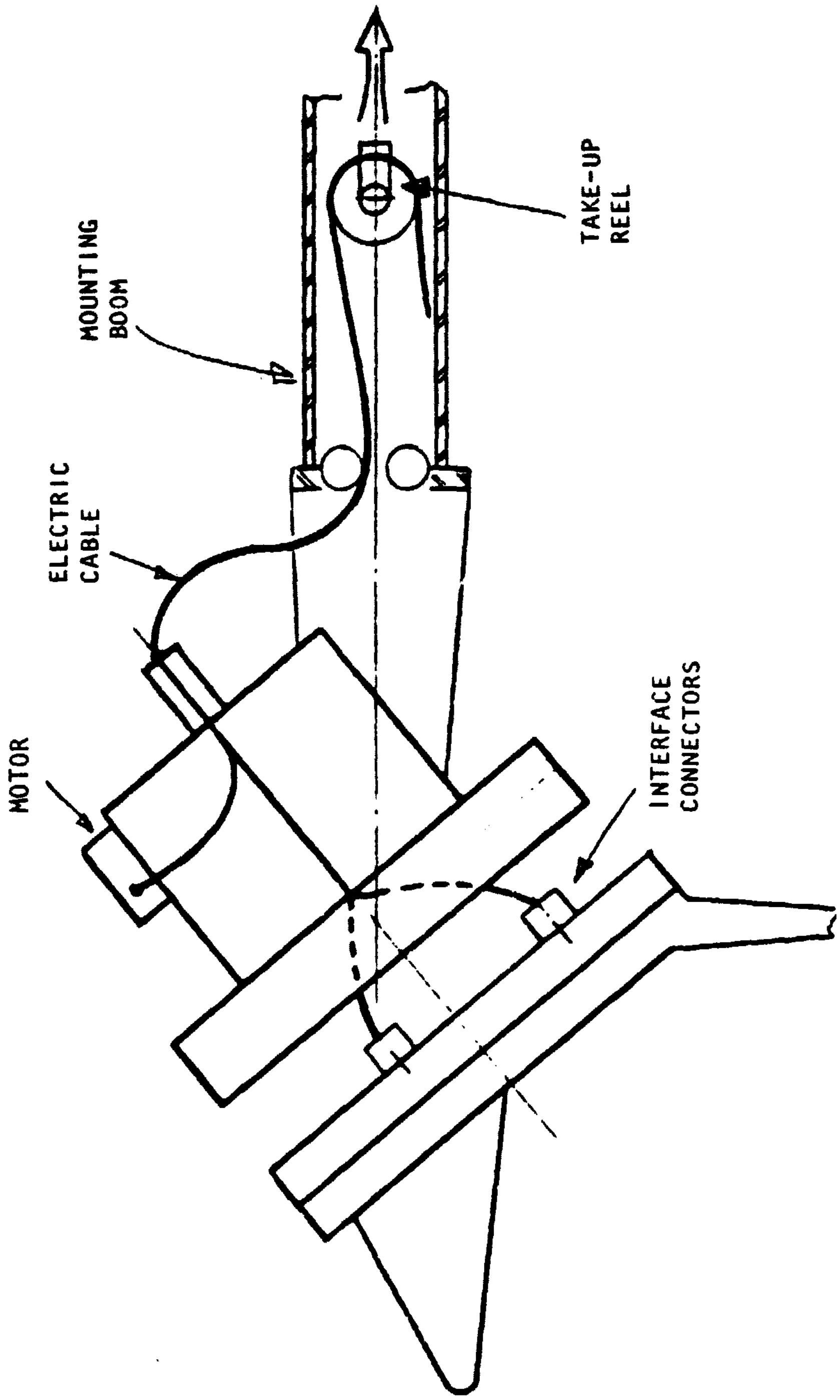
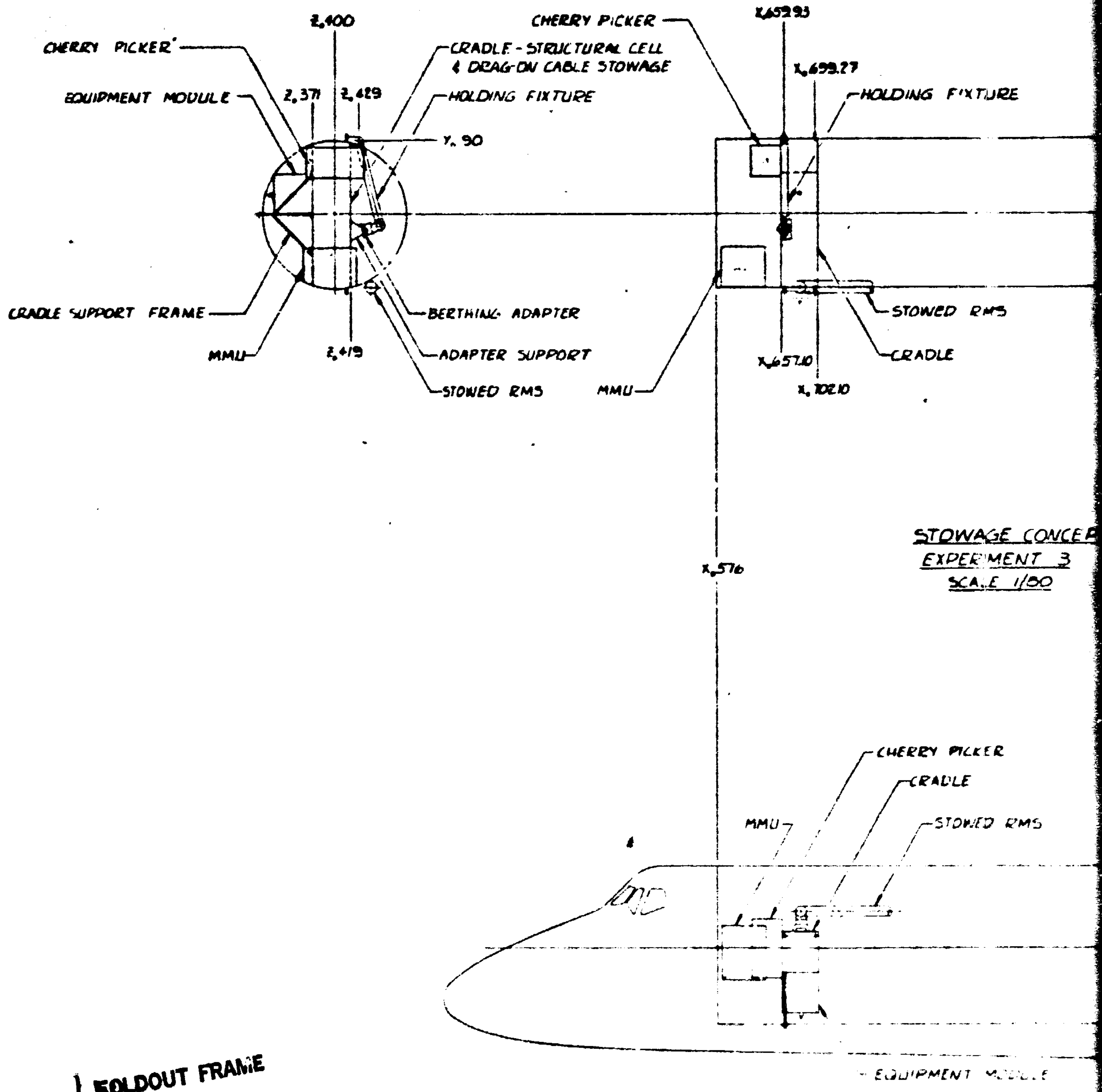
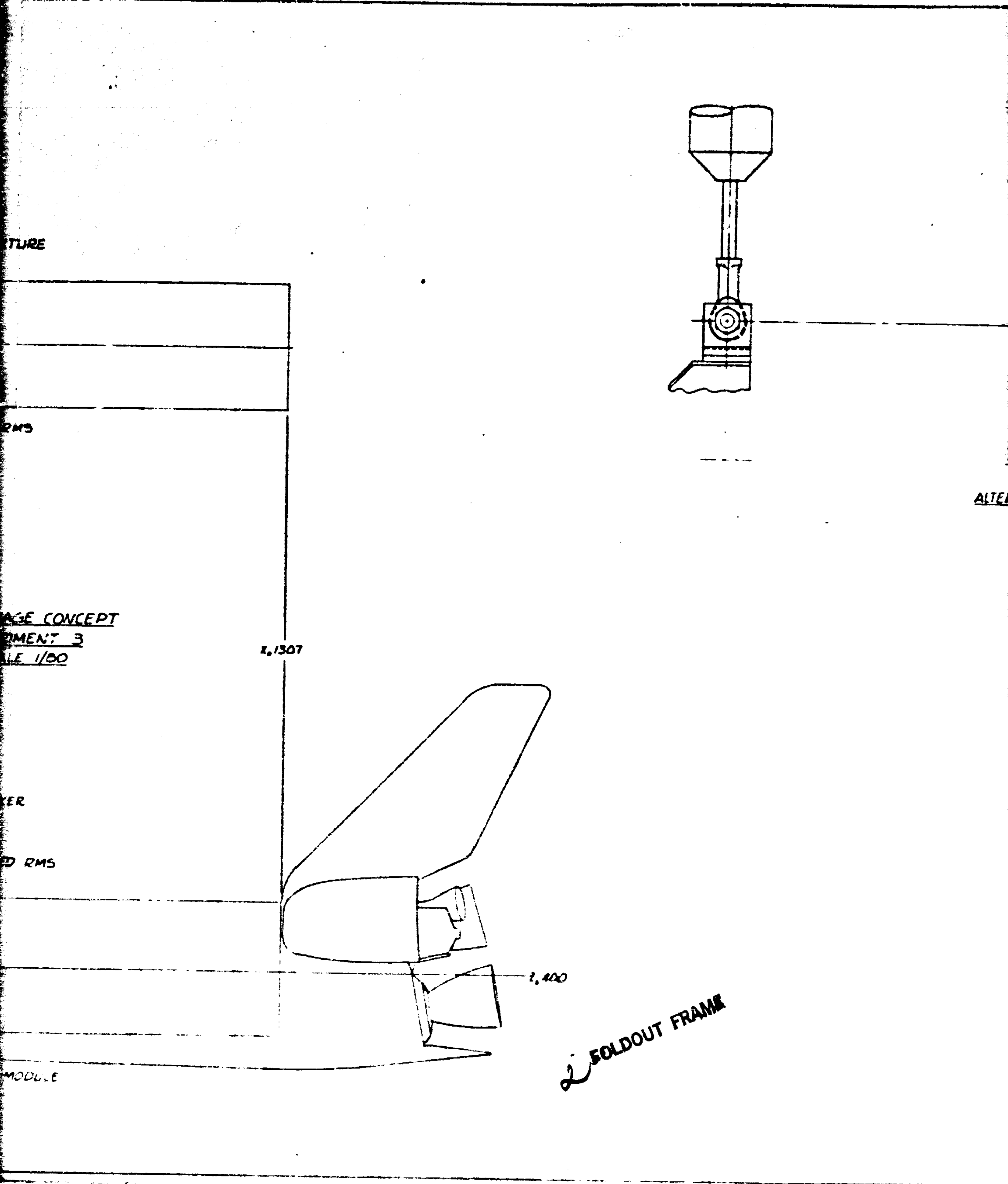


Figure 7-51. MPIDA Electrical Cabling

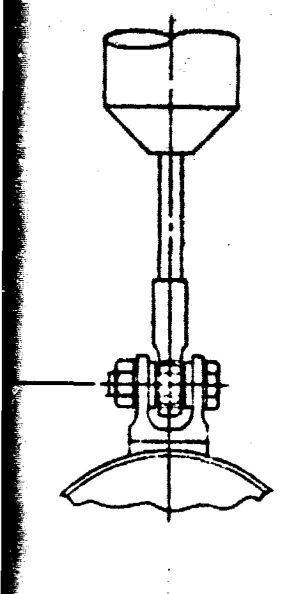


STOWAGE CONCEP
EXPERIMENT 3
SCALE 1/80

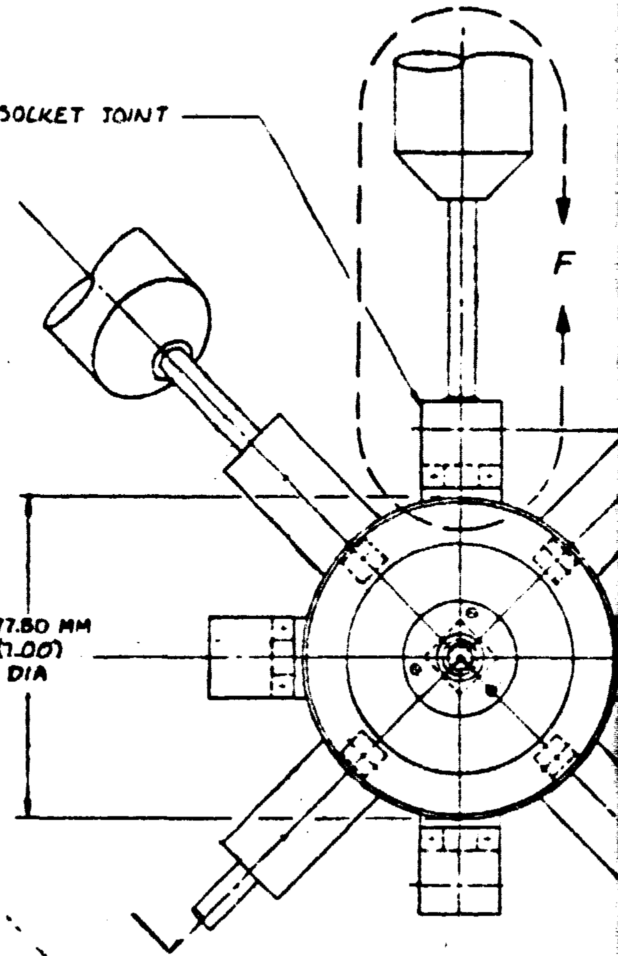
FOLDOUT FRAME



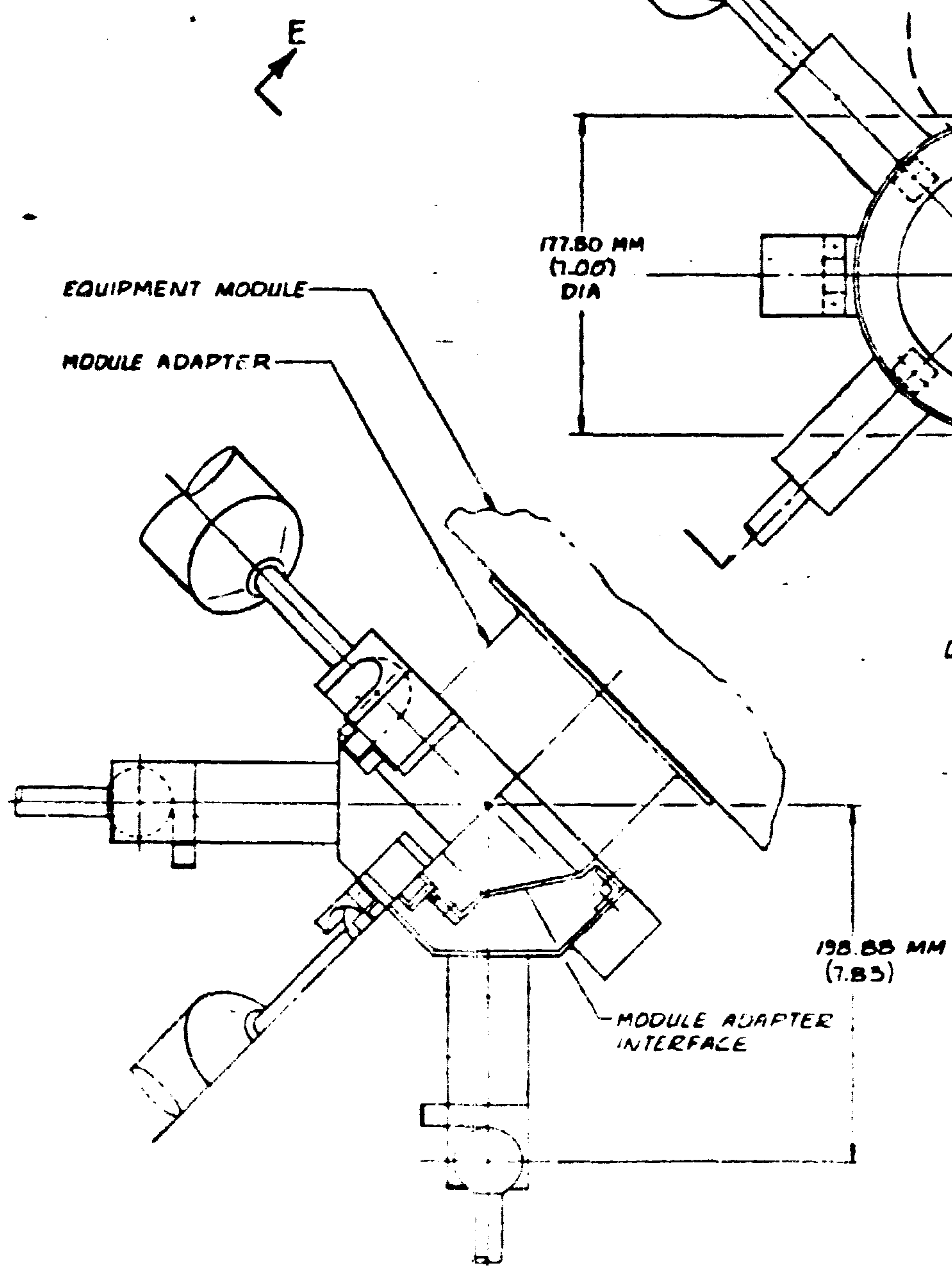
2 FOLDOUT FRAME



DETAIL F
[AL]TERNATE JOINT DESIGN
SCALE 1/2

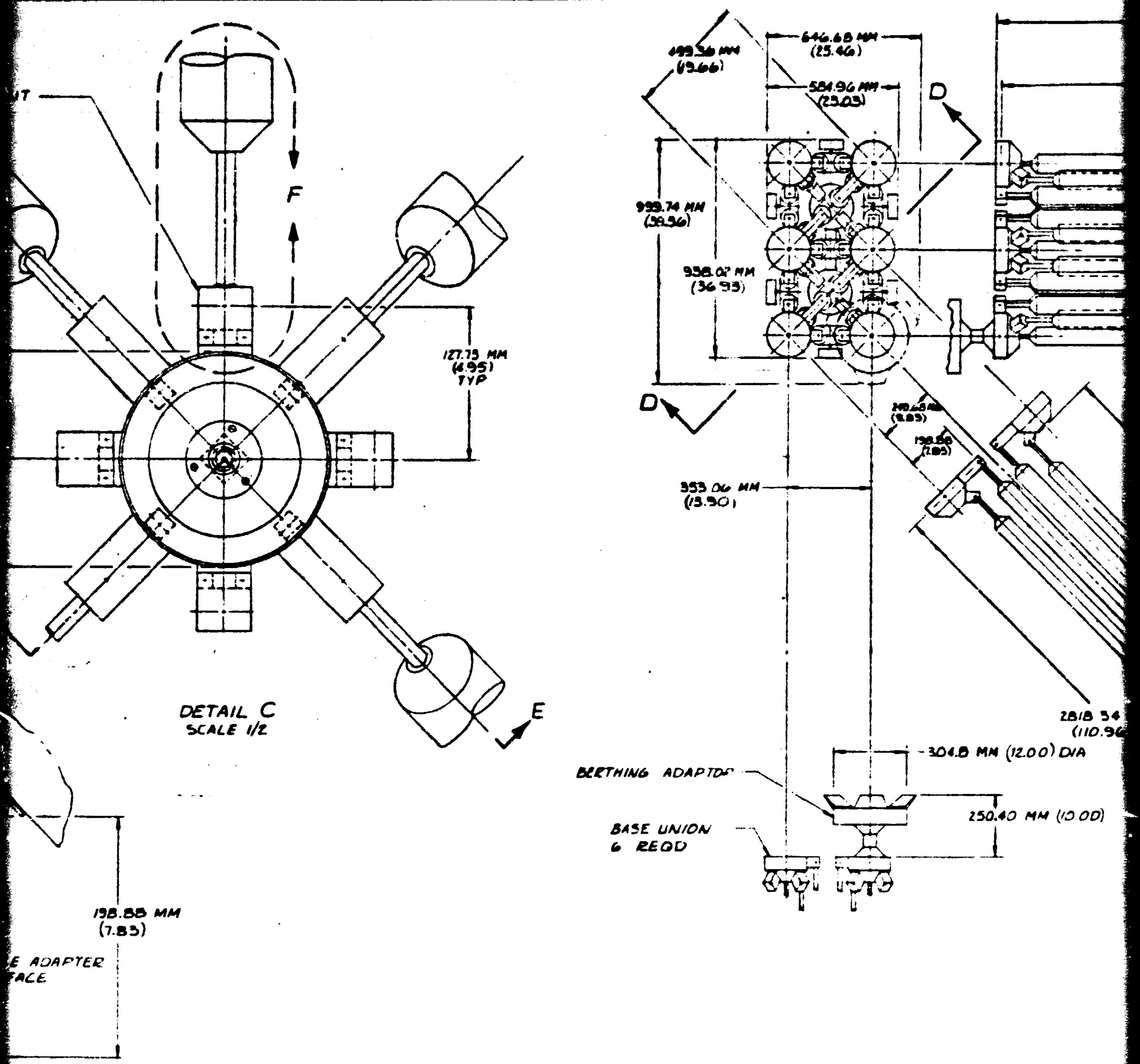


DETAIL C
SCALE 1/2

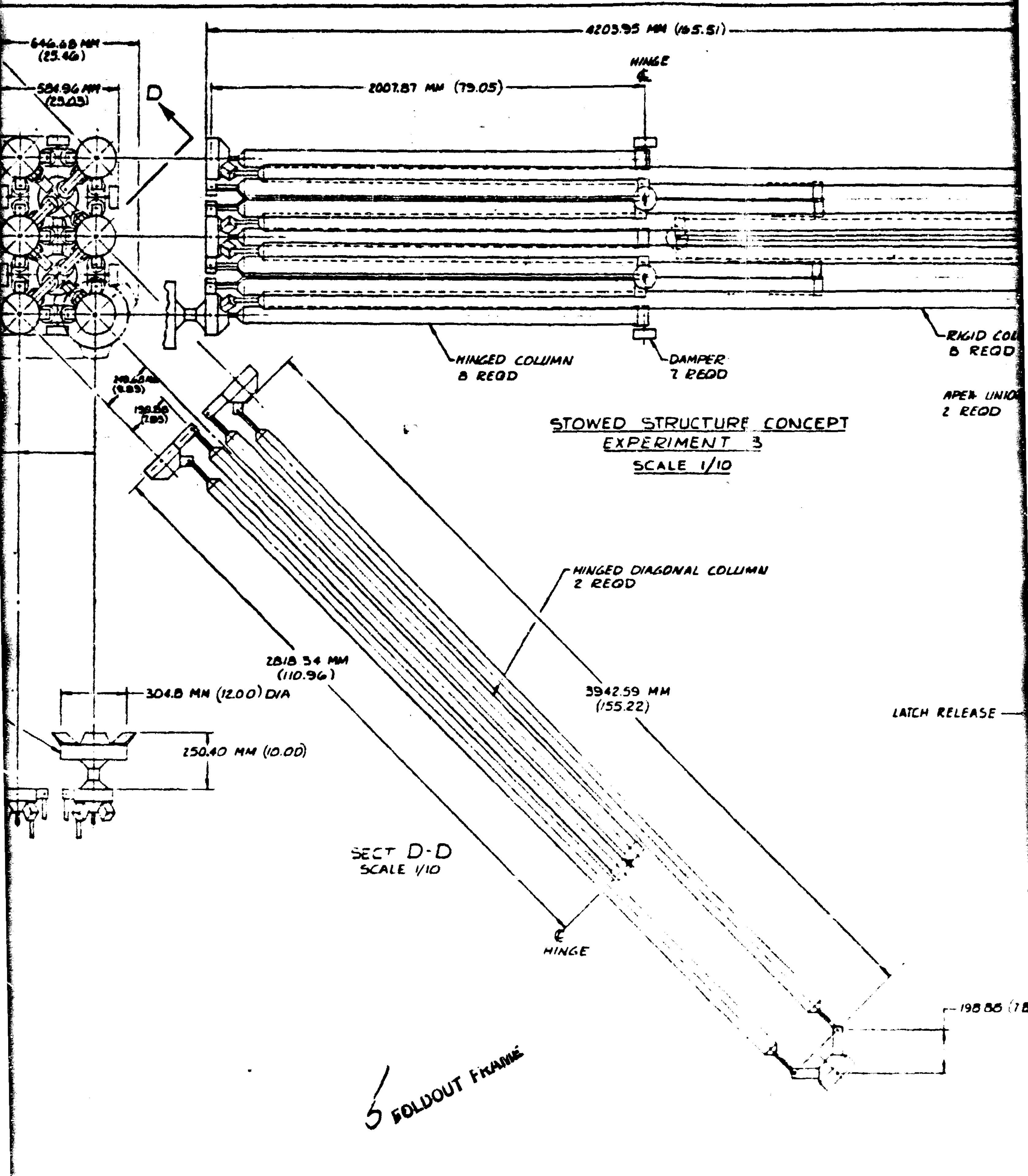


SECT E-E
SCALE 1/2

3 FOLDOUT FRAME

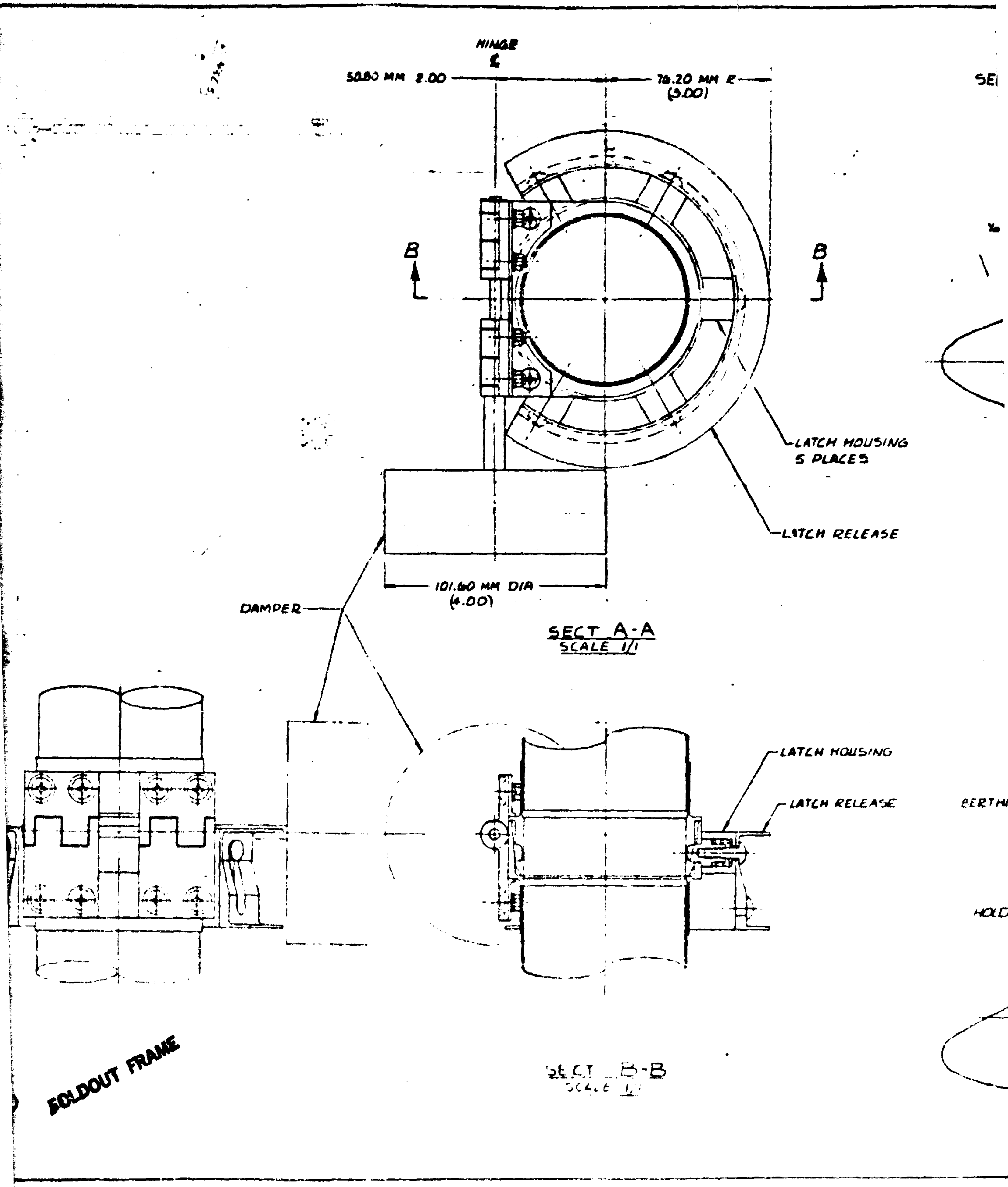


FOLDOUT FRAME



STOWED STRUCTURE CONCEPT
EXPERIMENT 3
SCALE 1/10

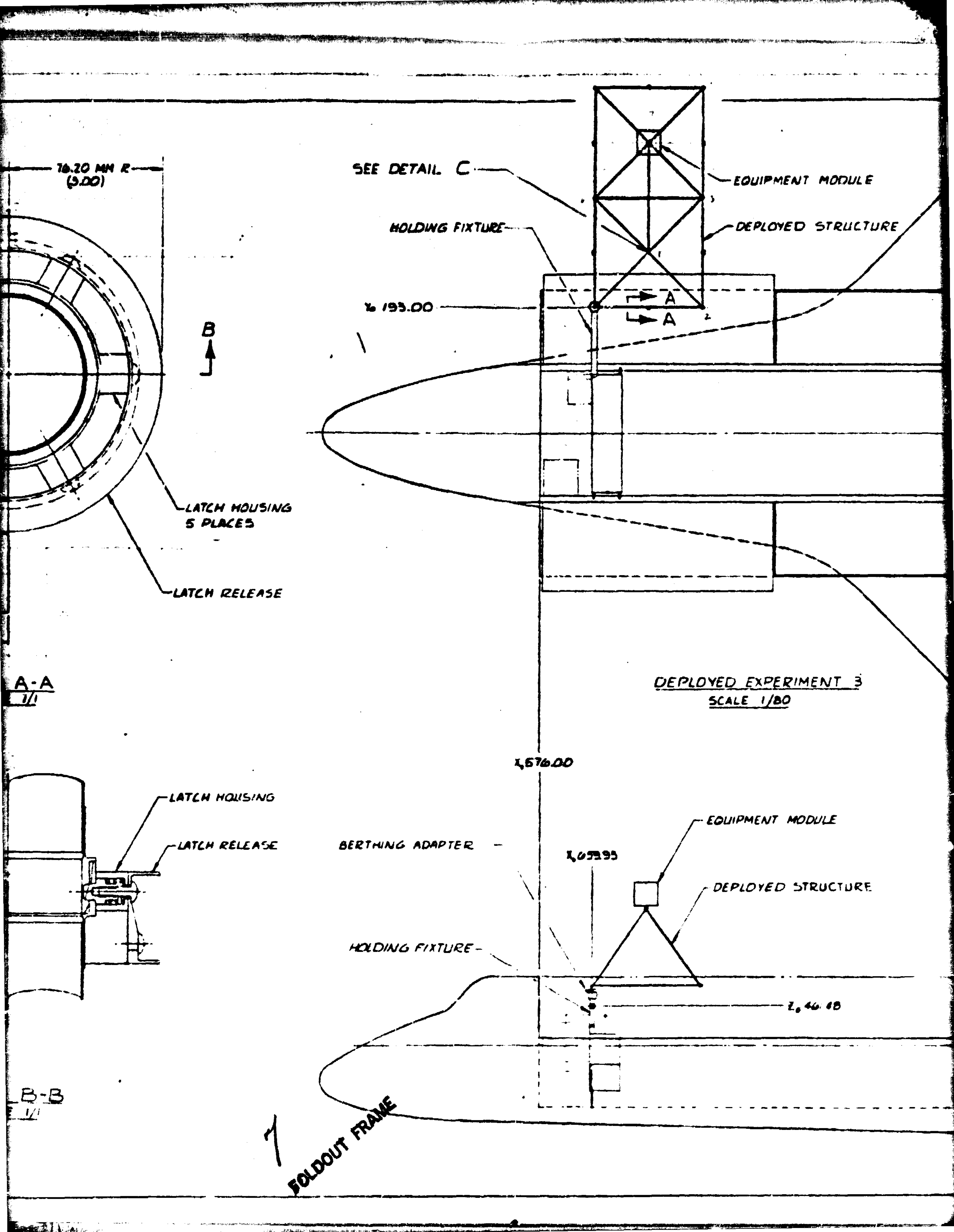
5 FOLDOUT FRAME

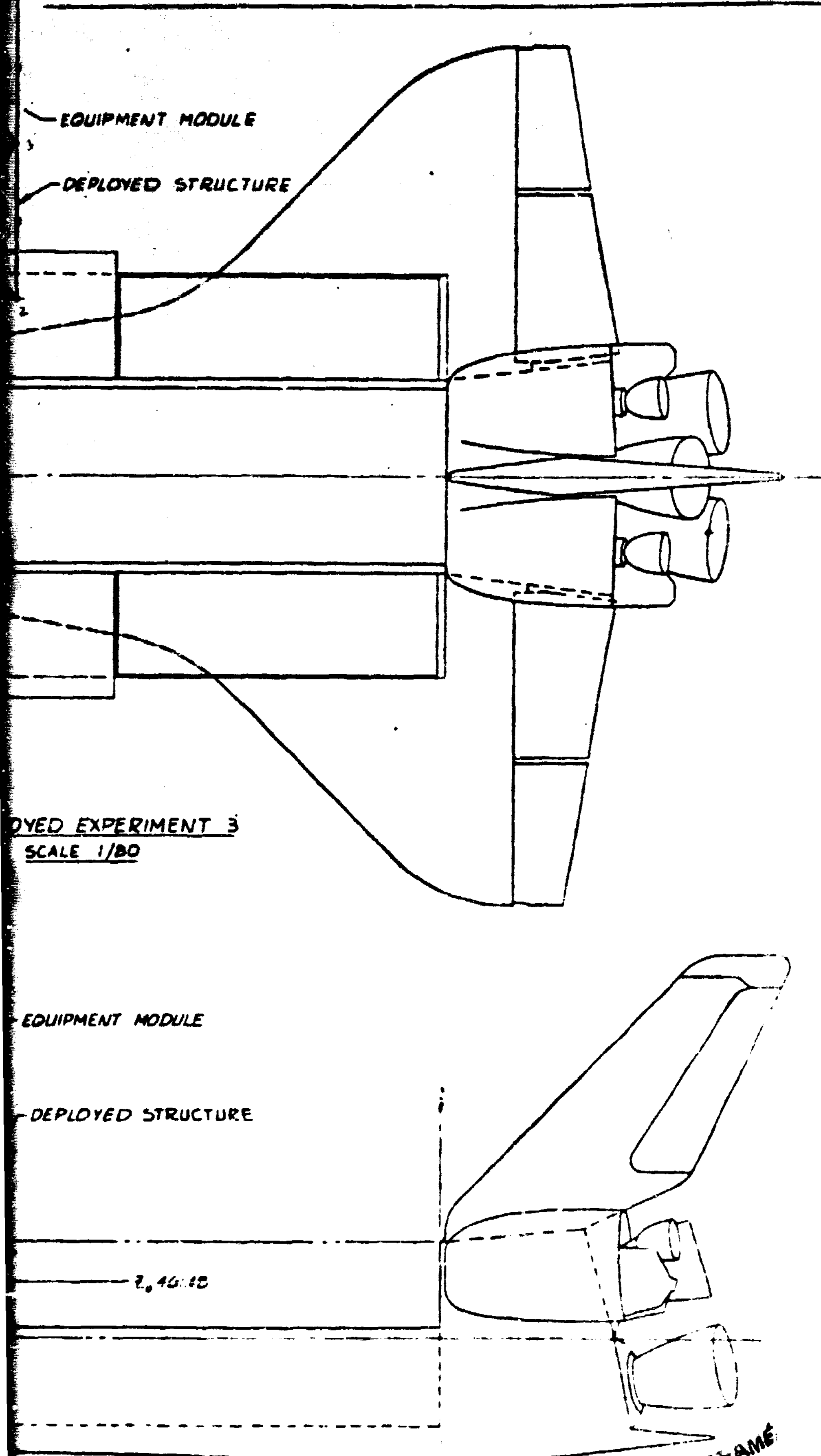


SECT A-A
SCALE 1/1

SECT B-B
SCALE 1/1

FOLDOUT FRAME


76.20 MM R
(3.00)
SEE DETAIL C
EQUIPMENT MODULE
DEPLOYED STRUCTURE
HOLDING FIXTURE
A
A
B
LATCH HOUSING
5 PLACES
LATCH RELEASE
A-A
1/1
DEPLOYED EXPERIMENT 3
SCALE 1/80
LATCH HOUSING
LATCH RELEASE
EQUIPMENT MODULE
BERTHING ADAPTER
DEPLOYED STRUCTURE
HOLDING FIXTURE
B-B
1/1
FOLDOUT FRAME



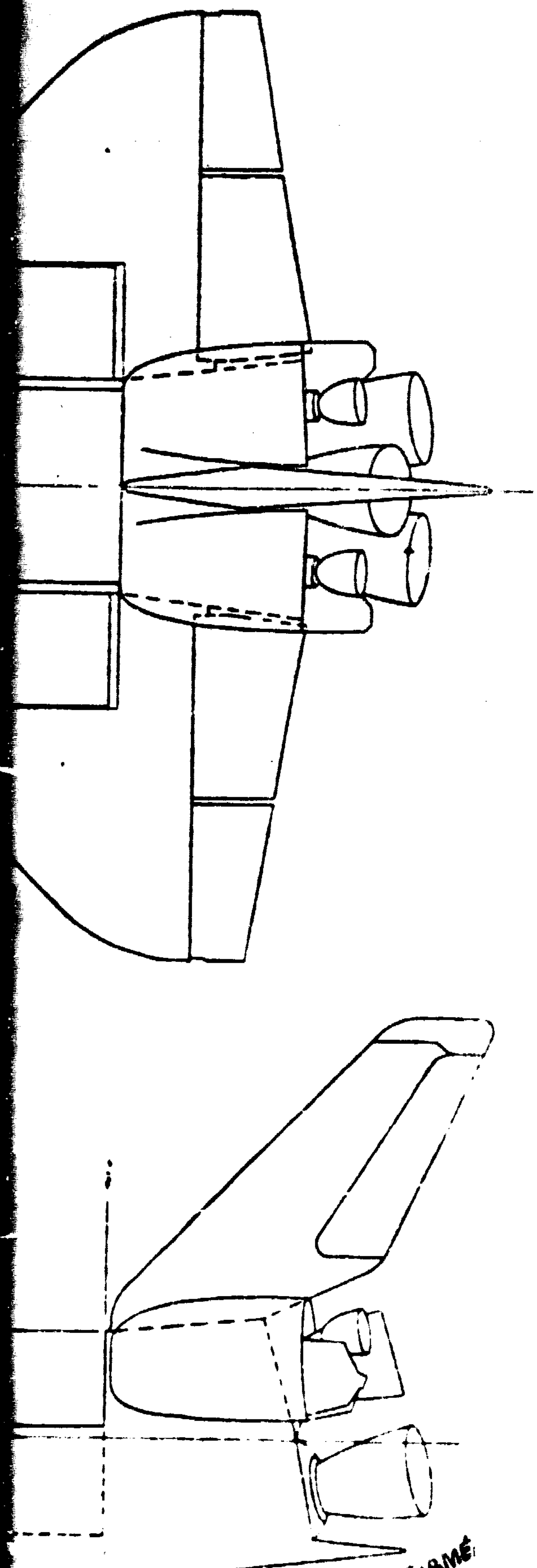
Figur

FOLDOUT FRAME

NOTED

ROCKWELL INTERNATI
SPACE DIVISION

DEPLOYED & STOWED



9 FOLDOUT FRAME

Figure 7-52.

REV 2 18 80 R.S.T.

NOTED	ROCKWELL INTERNATIONAL CORPORATION SPACE DIVISION	
FLIGHT EXPERIMENT NO. 3 DEPLOYED & STOWED CONFIG.		22602-76

2 FOLDOUT FRAME

The columns are made of 76.2 mm (3.0 in.) diameter tubular segments with the appropriate end joints and center hinges where applicable. The end joints can be of the ball-socket type, as shown in Detail C of Figure 7-52 or of the clevis-type, as shown in Detail F. Two end-joint pivot-point locations were established, one being 0.12 m (7.83 in.), as can be seen in Detail C of Figure 7-52. This was required to minimize the folded envelope of the structural cells.

The hinged columns utilize hinges based on the latch lock hinge concept which was designed, constructed, and successfully tested by Rockwell International under contract to NASA/LaRC and NASA/JSFC (References 7-2 and 7-3). The major elements of the hinge are seen in Section A-A of Figure 7-6 and are as follows:

- One fitting with five latch assemblies mounted on its outside periphery so that the tip of each square-shaped latch protrudes through a similarly square-shaped hole in its wall
- One passive fitting which is configured to depress the spring-loaded latches during column deployment and accept the latch in a special depression upon final column deployment
- A latch release ring which when moved axially causes the latches to withdraw from their depression and allows the hinge to be unlatched
- Two torsionally loaded hinge segments with a single hinge pin
- A damper which controls the rate of column deployment.

Equipment Module

The equipment module represents any type of mission equipment or subsystem module that requires attachment to the completed structure. In Experiment No. 3, the equipment module can be functional or nonfunctional. An active attachment adapter is incorporated into the module which requires an appropriate passive interface within the accepting union cavity. Such an interface is shown in Section E-E of Figure 7-52. The attachment adapter and its interface form a mechanical coupling which is a variation of a self-energized concept that was designed, constructed, and successfully tested by Rockwell International under contract to NASA/LaRC and NASA/MSFC (References 7-10 and 7-2). The original design is shown in Figure 7-53.

The probe half of the coupling attaches to the equipment module and drives an Acme threaded screw into a receiving nut as part of the passive interface. Two clock springs energize the screw which is held in the energized position by a ratchet until triggered by the insertion of the probe half into the interface and the application of a slight compressive force on it. The adapter can be disengaged for restowing purposes.

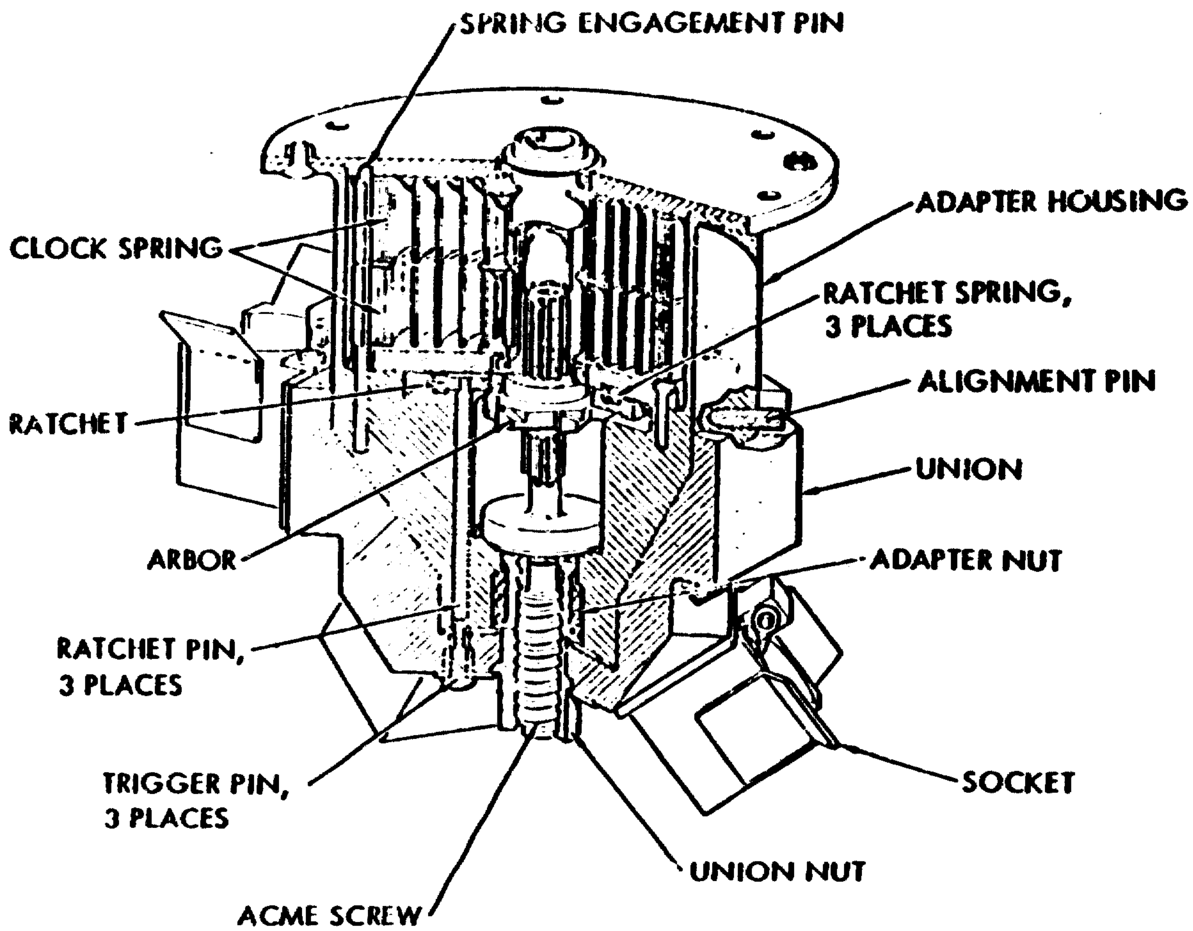


Figure 7-53. Self-Energized Adapter

Power and Signal Lines

In space construction activities involving platforms of various characteristics, whether fabricated, erected, or deployed, a significant aspect of the construction activity is expected to relate to the installation of adjunct equipment — lines, connections, jigs and fixtures, small hardware items — in addition to the scheduled installation of payload modules. There is at present little background for the scenario of operations and processes that would be required to implement these installations.

The power-and-signal-lines part of the experiment layout is shown in Figure 7-54 and consists of the plug-in installation of one duct section, the lay-on installation of two line sections, and the making of four electrical connections. The duct and cables will be stowed separately in the cargo bay. The actual design of the duct, attachment fittings, and cable connectors remains to be determined. Several attachment and routing concept studies have been under way at Rockwell International for NASA/LaRC (Reference 7-11). The typical concept outlined would provide test information relating to design and installation procedures. The RMS interface with the duct would be for a special end effector, one which has grasp capability plus a secondary activation function. The Goddard special-purpose end effector (SPEE) could meet this requirement (see Figure 7-55). The same end effector interface would be applicable to each end of the duct. The duct itself is a rectangular tray of composite materials to contain the electrical wiring and integrate with the end fixtures (connectors and latch).

The duct attachment at Union 1 is as shown in Figure 7-56. The RMS inserts the duct connector plate onto the structure mounted plate, and using the SPEE screws it into place to effect both mechanical and electrical connections. The connector plate contains in the order of 100 pins sized for No. 16-gauge wire. Total engagement force should be in the range of 250 pounds (1112 N). This represents a test equivalent of a lay-on duct connection of power, data, and coolant connectors for a small-scale payload platform. The connection at Union 1 would provide power and signal lines to the docking adapter or to a subsystem payload which could be installed to the underside face of the union fitting. Figure 7-56 shows a second type of passive connection which is only a structural interface between the duct and the capability of the RMS to lay on relatively flexible lines depends on its ability to engage and manipulate different attachment locations on the line as installation progresses along the lay-on path. The release and reengagement of the flexible line is extremely questionable. A line lay-on canister is proposed to permit this type of installation. If a cable is stowed with an overlay double coil as shown in Figure 7-57, it can be deployed to a straight section without any cable twist, either coiled or deployed. Eight No. 16 wires could be easily coiled with an 8-inch radius, resulting in a stowed width of about 16 inches and a spacing of the attachment clamps of about 8 inches (0.2 m). This represents a stowed length ratio of 1:13 (13 meters of cable can be stowed in a length of 1 meter). The attachment clamps, spaced 8 inches apart, are installed in a canister (tray) as shown in Figure 7-57 ready to be engaged in sequence to a column without the RMS having to release and reengage the flexible line.

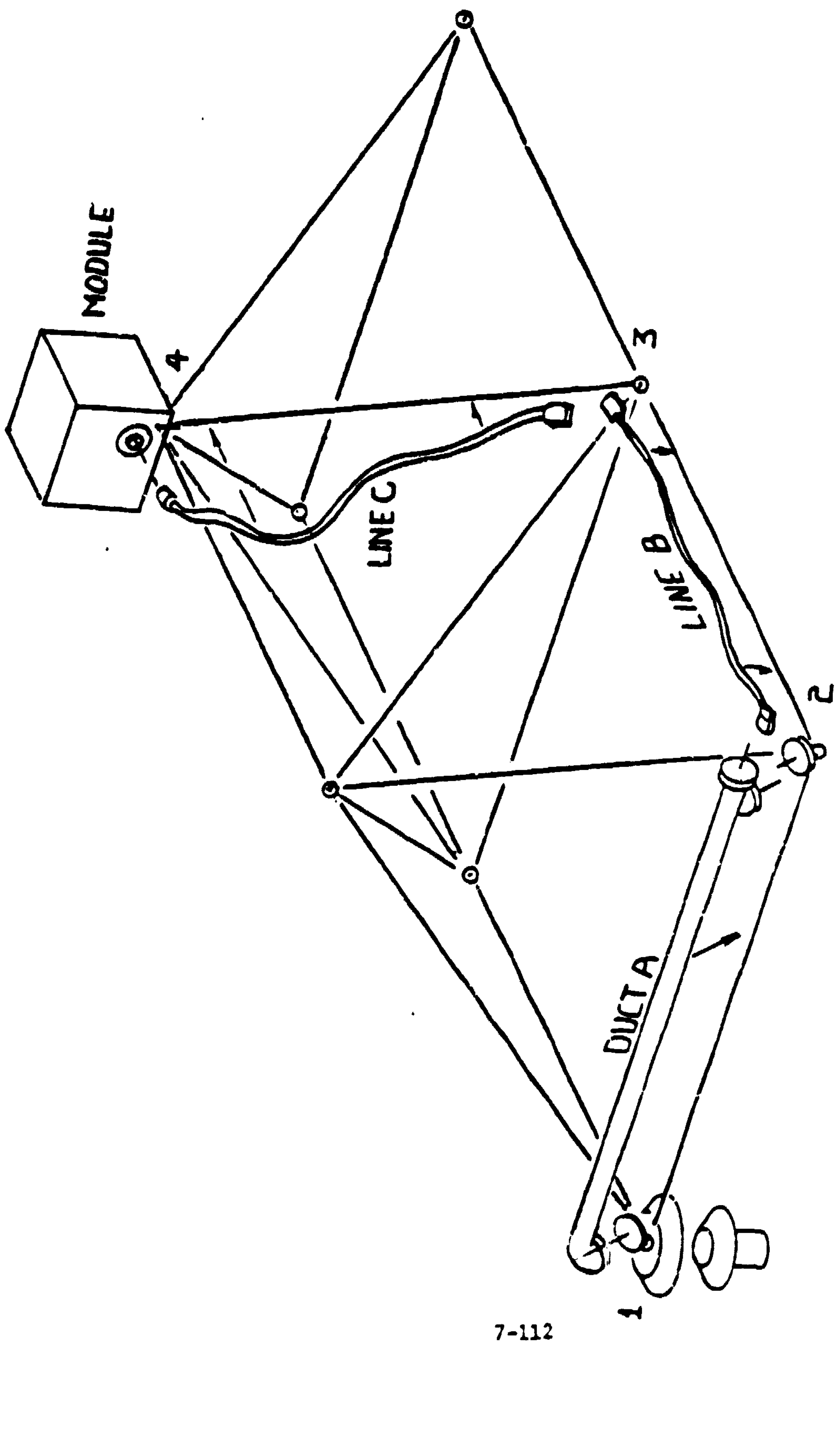


Figure 7-54. Schematic of Power/Signal Lines Layout

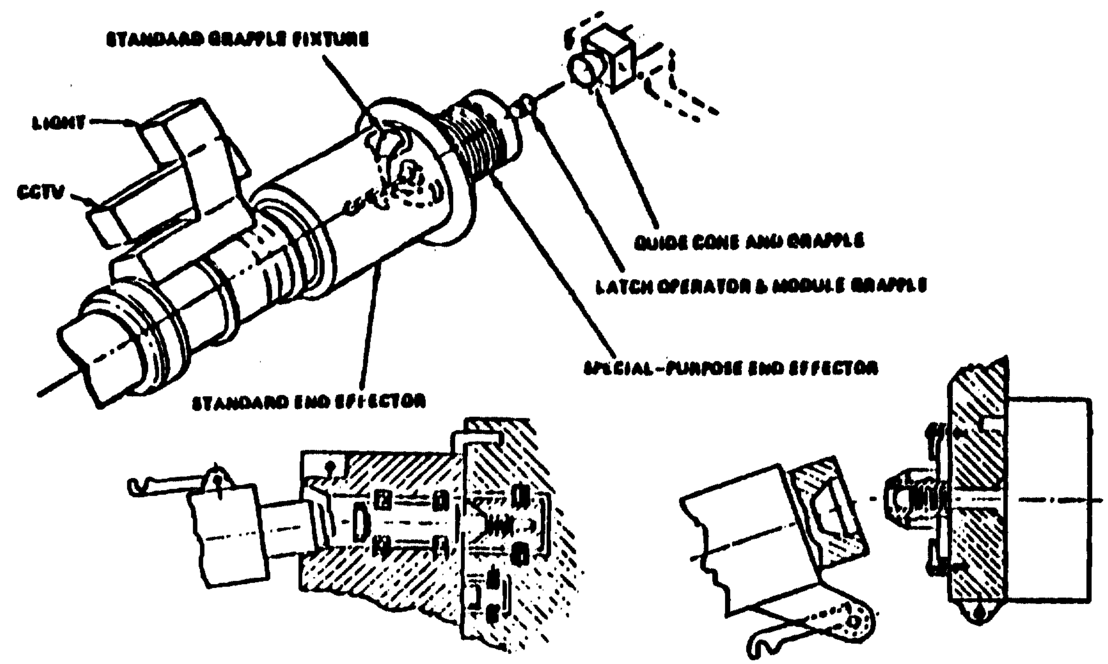


Figure 7-55. Special-Purpose End Effector

C-3

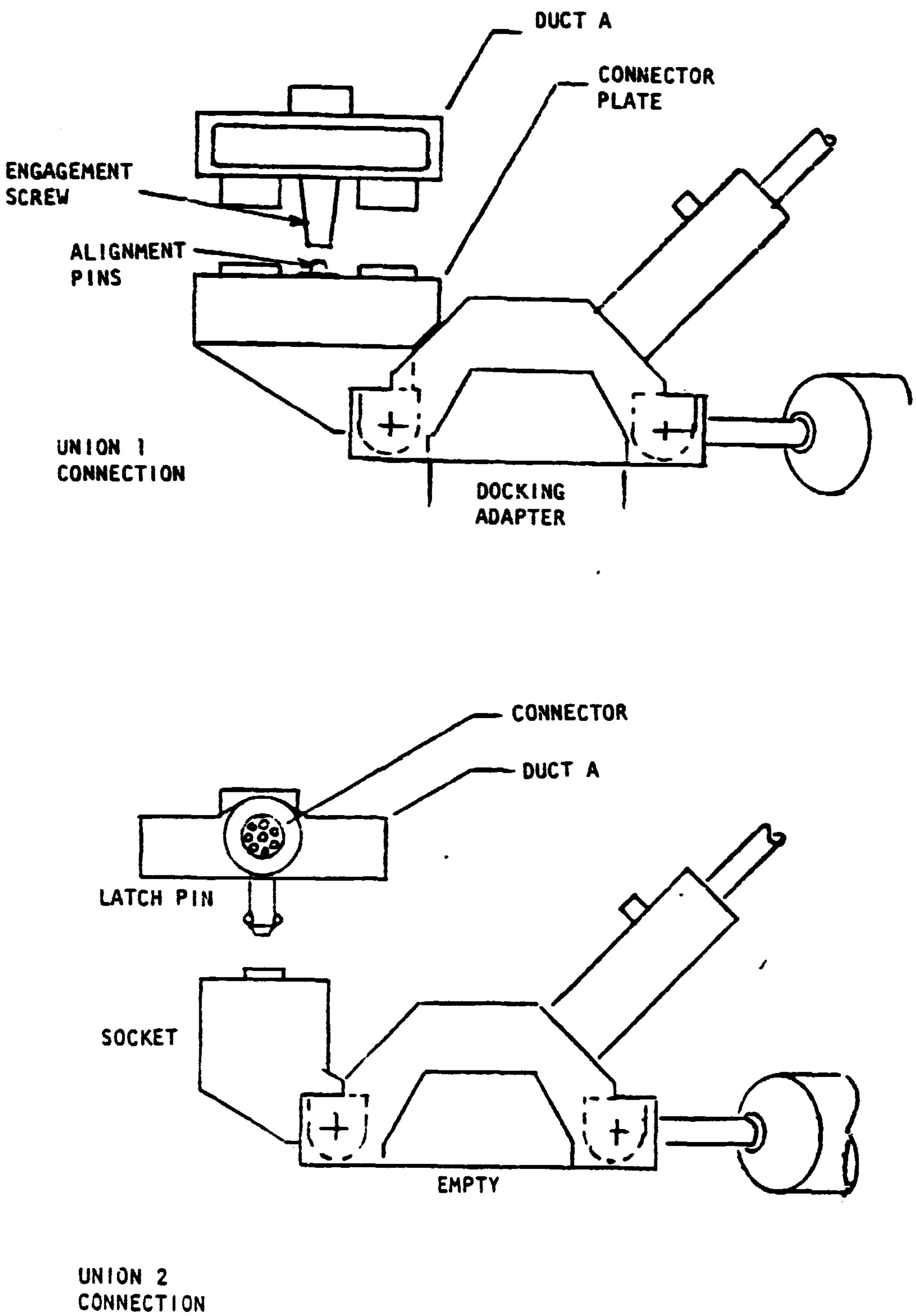


Figure 7-56. Duct Connector Interfaces

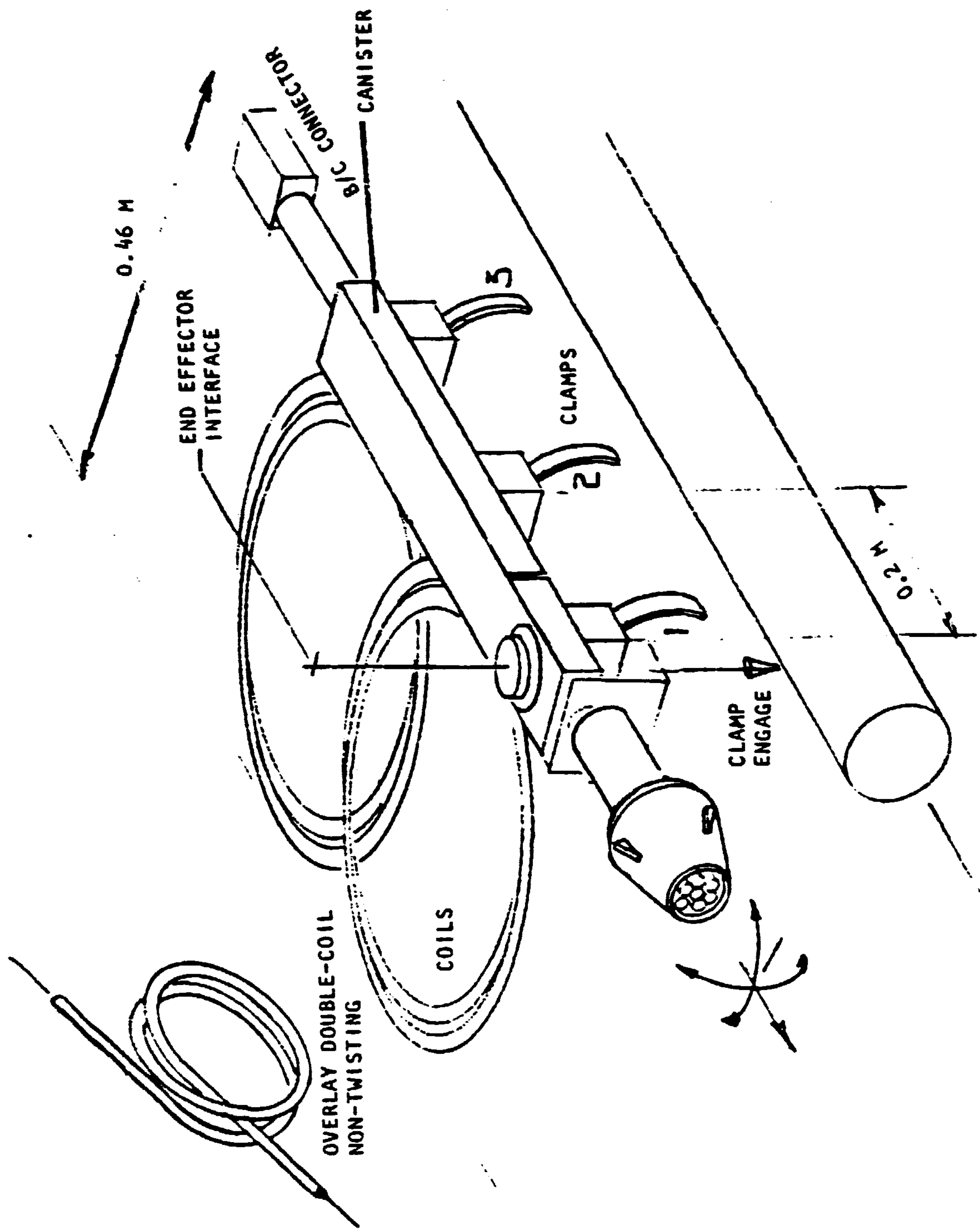


Figure 7-57. Canister for Deploying Flexible Power/Signal Lines

The canister holds the clamp along the top and one side in a rail configuration, as shown in Figure 7-58, with the canister holding a release pin from extending. All the clamps are prevented from latching to the column because the latch is restrained. As the clamps are pulled to the end effector interface section by the extension of the previous cable coil, the RMS engages the next clamp to the column and releases the small section of side panel permitting the clamp to be latched to the column and released from the canister. The SEE previously used for duct lay-on could perform this secondary release function on command.

The connector latch cone and connector plug (Figure 7-57) can swivel in two axes independent of the canister block for ease of insertion alighment.

Experiment No. 3 Stowage

The packaging of Experiment No. 3 was designed to minimize the length required for its stowage within the orbiter cargo bay. As shown in Figures 7-44 and 7-52, the MMU is stowed in its assigned position. The folded structure and the electrical cable are stowed within a container-cradle that stretches across the cargo bay with a cross section of 1143 mm (45.00 in.) wide and 1219 (48.00 in.) deep. The trunnions that support the container cradle on sliding rails similar to those of a file cabinet drawer rails. The rails will be mounted on a lazy-susan type support to facilitate the deployment of the equipment module by the RMS. The cherry picker is stowed on the forward side of the container-cradle on the starboard side where it is easily accessible to the RMS. The holding fixture is really mounted on the trunnion that supports the container-cradle. The arm is laid across the container cradle where there is a support that latches onto the berthing adapter during Shuttle launch and reentry.

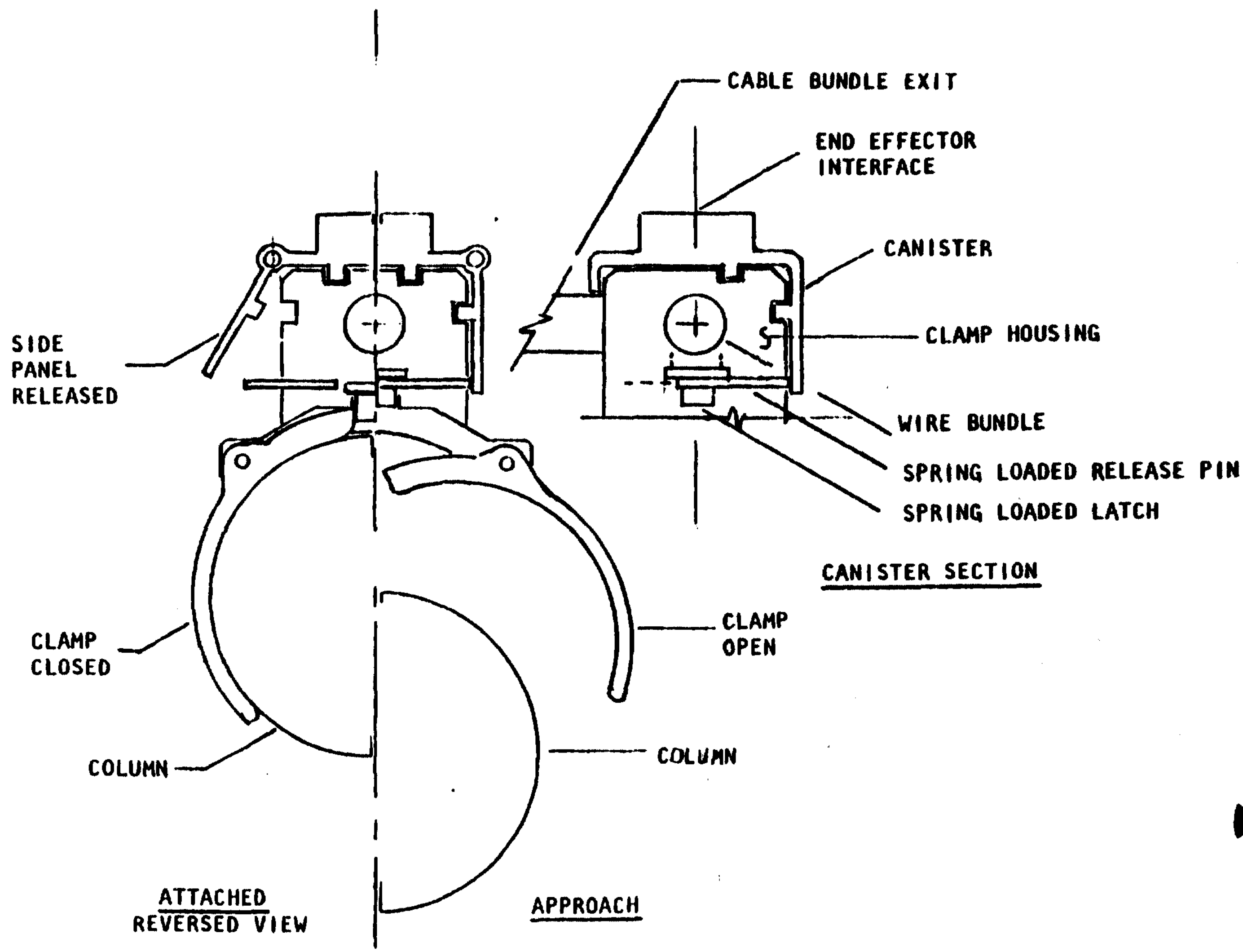


Figure 7-58. Attachment Clamps for Power/Signal Lines

7.3.2 Mission Scenario

This experiment is concerned with the validation and performance effectiveness of a series of construction equipment aids and the installation of equipment modules and power/signal lines. The time estimates for the individual RMS and EVA operation elements are those quoted in Table 7-4 .

The overall mission has been divided into 12 major operational tasks (see Table 7-15); a brief description of each task is outlined below.

TASK 1, which prepares the RMS for operation, will power up, release, and check out the RMS. The time allocated for this preparation is 24 minutes, which is identical with Experiment No. 2.

TASK 2 is involved with releasing, power-up, and checkout of the handling and positioning aid (HAPA). This device has similar features to the RMS and would require the similar start-up procedures and take another 24 minutes. The HAPA is stowed on top of the equipment container, as shown in Figure 7-59.

TASK 3 will use the RMS and end effector to berth with the cherry picker which is installed at the forward station of the orbiter's cargo bay. The power-up and checkout of the cherry picker is achieved remotely by the AFD consoles. The EVA astronaut next enters the cherry picker platform station and disengages it from the Shuttle retention device. The controls for the RMS are switched to the cherry picker work station and the astronaut performs the necessary checkout operations and maneuvers the cherry picker out of the cargo bay. The time allocated for this task is about 26 minutes, which is compatible with the checkout time of the RMS.

TASK 4 releases and deploys the structure module with the aid of the EVA astronaut aboard the cherry picker. The RMS moves to the container and the EVA astronaut assists in releasing the restraint latches of the container and the structure module inside the container. The structure module is grasped by the payload transport device aboard the cherry picker and removed from its container and maneuvered to the starboard side of the cargo bay where it is berthed to the payload holding and positioning aid (HAPA). The cherry picker moves to the top of the bundled structure module and proceeds to release the fitting constraining the two top modes together. Figure 7-60 shows the structure module partially displayed using the RMS only. This procedure can be adopted in lieu of the cherry picker operation. In fact, this RMS operation is employed in a later task involved with repacking the structure module. Once the top nodes have been deployed and locked into position, the cherry picker is transferred to the base of the strut module near the berthing interface and releases a second restraining fitting which allows the remaining nodes to fully deploy the structure as shown in Figure 7-61. The cherry picker is moved to the center hinge joints where the EVA astronaut ensures that each hinge is fully locked. The total time for this task has been estimated to be 67 minutes

TASK 5 installs three power and signal cables and makes the necessary connections (Figure 7-62). The initial cable is the long rigid duct which is removed from its tie-down position inside the experiment container and

Table 7-15. Time Estimates for Timeline Operational Tasks in Mission Scenario

DESCRIPTION OF OPERATION		TIME (MINUTES)
1.	PREPARING RMS FOR OPERATION	
1.1	PREPARE GPC's FOR RMS OPERATION	3.5
1.2	MANEUVER TO DEPLOYMENT ATTITUDE	6.5
1.3	POWER UP MANIPULATOR ARM HEATERS	(6.5)
1.4	POWER UP, CHECK OUT CCTV/LIGHTS	(5.0)
1.5	POWER UP MANIPULATOR - UNLOCK HAND CONTROLLERS	(1.0)
1.6	STABILIZE - FREE DRIFT - RCS OFF	(1.0)
1.7	PERFORM MANIPULATOR ARM STATIC CHECKOUT	5.0
1.8	ROTATE MANIPULATOR ARM - RELEASE RESTRAINTS	2.0
1.9	SELECT AUTO PROGRAM - DEPLOY MANIP. ARM	1.5
1.10	PERFORM MANIP. FUNCTIONAL CHECKS	5.0
1.11	SELECT/VERIFY MANUAL AUG. CONTROL	0.25
	TOTAL TIME	24.00
2.	PREPARING HAPA FOR OPERATION	
2.1	PREPARE GPC's FOR OPERATION	3.5
2.2	POWER UP HAPA HEATERS	6.5
2.3	POWER UP HAPA - UNLOCK HAND CONTROLLERS	1.0
2.4	PERFORM HAPA STATIC CHECKOUT	5.0
2.5	RELEASE RESTRAINTS AND ROTATE HAPA	2.0
2.6	SELECT AUTO PROGRAM - DEPLOY HAPA	1.5
2.7	PERFORM HAPA FUNCTIONAL CHECKS	5.0
2.8	SELECT/VERIFY MANUAL CONTROL	0.25
	TOTAL TIME	24.24
3.	ATTACH AND PREPARE MANNED REMOTE WORK STATION (CHERRY PICKER) FOR OPERATION	
3.1	RMS GRAPPLES	10.0
3.2	REMOTE CHECKOUT OF MRWS SUBSYSTEMS	10.0
3.3	EVA CREW ENTER MRWS	3.0
3.4	DISENGAGE MRWS/SHUTTLE RETENTION DEVICE	1.0
3.5	MANEUVER TO MRWS WORK STATION	2.0
	TOTAL TIME	26.0
4.	RELEASE AND DEPLOY STRUCTURE MODULE	
4.1	MOVE END EFFECTOR TO TOP LID OF CONTAINER BOX	1.50
4.2	DOCK END EFFECTOR WITH ATTACHMENT POINT ON LID & GRAPPLE	2.50
4.3	RELEASE CONTAINER LID HOLD DOWN LATCHES	0.25
4.4	MOVE END EFFECTOR TO OPEN CONTAINER LID	1.50

Table 7-15. (Continued)

	DESCRIPTION OF OPERATION	TIME (MINUTES)
4.5	SELECT ORBITER-REF. COORD. SYSTEM	0.25
4.6	M/A MODE MOVE END EFFECTOR TO STOWED STRUCTURE	1.50
4.7	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.8	DOCK END EFFECTOR TO GRAPPLE FIXTURE ON STOWED STRUCTURE	2.50
4.9	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.10	RELEASE LATCHES AND RESTRAINING CLAMPS AROUND STRUCTURE	0.25
4.11	WITHDRAW STRUCTURE ASSEMBLY FROM INSIDE OF CONTAINER BOX	1.50
4.12	MOVE MODULE TO STARBOARD SIDE OF CARGO BAY	1.50
4.13	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.14	ROTATE STRUCTURE MODULE TO VERTICAL POSITION	0.50
4.15	DOCK WITH STARBOARD CONSTRUCTION HOLDING FIXTURE AND LOCK	2.50
4.16	RELEASE GRAPPLE FIXTURE AND BACK AWAY	1.00
4.17	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.18	MOVE END EFFECTOR TO OTHER END OF STRUCTURE MODULE	1.50
4.19	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.20	DOCK TO GRAPPLE FITTING USED FOR RESTRAINING END UNIONS	2.50
4.21	RELEASE UNION RESTRAINTS AND BACK AWAY RMS	1.00
4.22	ALLOW STRUTS TO DEPLOY AND CENTER HINGES TO LOCK	2.00
4.23	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.24	MOVE TO CENTER HINGE #1	1.50
4.25	ASSURE HINGE #1 IS LOCKED	1.00
4.26	REPEAT OPERATIONS FOR HINGES 2 THROUGH 8	17.50
4.27	MOVE TO NODE #1 ON EXTENDED STRUT BASE	1.50
4.28	SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
4.29	DOCK WITH GRAPPLE ATTACHMENT AT NODE #1	2.50
4.30	RELEASE BELTING LATCHES SECURING MODULE TO STARBOARD CONSTRUCTION HOLDING FIXTURE	0.25
4.31	LIFT MODULE AWAY FROM FIXTURE	1.50
4.32	ROTATE END EFFECTOR WRIST 180° TO TURN STRUCTURAL MODULE RIGHT SIDE UP	0.50
4.33	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.34	MOVE NOD #1 TOWARDS STARBOARD CONSTRUCTION HOLDING FIXTURE	1.50
4.35	SELECT END EFFECTOR COORD. SYSTEM	0.25
4.36	DOCK NODE #1 WITH CONSTRUCTION HOLDING FIXTURE AND SECURE STRUCTURE MODULE	2.50
4.37	RELEASE GRAPPLE FIXTURE AND BACK AWAY	1.00
4.38	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.39	MOVE RMS END EFFECTOR TO TOP STRUCTURAL NODE OF STRUCTURE MODULE	1.50
4.40	SELECT END EFFECTOR COORD. REF. SYSTEM	0.25
4.41	DOCK WITH GRAPPLE FITTING USED FOR RESTRAINING TOP UNIONS	2.50
4.42	RELEASE UNION RESTRAINTS AND LOCK AWAY RMS	1.00
4.43	ALLOW STRUCTS TO DEPLOY AND CENTER HINGES TO LOCK	2.00
4.44	SELECT ORBITER REF. COORD. SYSTEM	0.25
4.45	MOVE TO TOP CENTER HINGE AND VERIFY HINGE IS LOCKED	2.5
	TOTAL TIME	67.0

Table 7-15. (Continued)

DESCRIPTION OF OPERATION	TIME (MINUTES)
5. INSTALL CABLES AND MAKE CONNECTIONS	
5.1 SELECT ORBITER REF. COORD. SYSTEM	0.25
5.2 MOVE END EFFECTOR TO DUCT CONTAINER	1.50
5.3 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
5.4 DOCK AND GRAPPLE WITH DUCT CONTAINER	2.50
5.5 RELEASE DUCT CONTAINER RESTRAINT LATCHES	0.25
5.6 MOVE TO CONSTRUCTION HOLDING FIXTURE	1.50
5.7 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
5.8 DOCK AT CONSTRUCTION HOLDING FIXTURE	2.50
5.9 MAKE ELECTRICAL CONNECTION AT UNION NO. 1	1.00
5.10 MOVE RMS TO OTHER END OF DUCT	3.50
5.11 MAKE ELECTRICAL CONNECTION AT UNION NO. 2	1.00
5.12 SELECT ORBITER REF. COORD. SYSTEM	0.25
5.13 MOVE END EFFECTOR TO CABLE CONTAINER	1.50
5.14 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
5.15 DOCK AND GRAPPLE WITH CABLE CONTAINER	2.50
5.16 RELEASE CABLE CONTAINER RESTRAINT LATCHES	0.25
5.17 REMOVE CABLE CONTAINER FROM P/L	1.00
5.18 MOVE TO CONSTRUCTION HOLDING FIXTURE	1.50
5.19 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
5.20 DOCK AT CONSTRUCTION HOLDING FIXTURE	2.50
5.21 MAKE ELECTRICAL CONNECTION	1.00
5.22 MOVE ALONG STRUTS, PLAY OUT CABLE AND ATTACH TO STRUTS	5.00
5.23 EVA AND MMU MOVE TO CARGO BAY	1.50
5.24 RELEASE RESTRAINT LATCHES AND REMOVE CABLE	1.00
5.25 EVA MOVE TO TEST STRUCTURE	1.50
5.26 ATTACHES CABLE TO STRUCTURE AND MAKES ELECTRICAL CONNECTION	3.00
5.27 TEST FOR CONTINUITY	1.50
5.28 REMOVE CABLES AND REPEAT SOME OF OPERATIONS UNDER ATTITUDE HOLD CONDITION WITH ORBITER	16.00
5.29 REMOVE CABLE AND REPEAT SOME OF ABOVE OPERATIONS UNDER ATTITUDE REORIENTATION	16.00
TOTAL TIME	71.00
6. EVA/CHERRY PICKER INSTALL SUBSYSTEM MODULE	
6.1 SELECT ORBIT REF. COORD. SYSTEM	0.25
6.2 MOVE END EFFECTOR TO STOWED POSITION OF SUBSYSTEM MODULE	1.50
6.3 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
6.4 DOCK AND GRAPPLE WITH SUBSYSTEM MODULE	2.50
6.5 RELEASE SUBSYSTEM MODULE RESTRAINT LATCHES AND REMOVE	1.25
6.6 MOVE TO APEX OF STRUCTURE MODULE	1.50
6.7 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
6.8 DOCK WITH STRUCTURE MODULE	2.50
6.9 INSTALL SUBSYSTEM MODULE AND CHECK-OUT	3.00

Table 7-15. (Continued)

DESCRIPTION OF OPERATION	TIME (MINUTES)
6.10 REMOVE SUBSYSTEM MODULE AND BACK AWAY	6.00
6.11 REPEAT LAST TWO OPERATIONS UNDER ATTITUDE HOLD AND ATTITUDE REORIENTATION	22.00
TOTAL TIME	41.00
7. REMOVE CABLES AND SUBSYSTEM MODULE	
7.1 MOVE END EFFECTOR TO CABLE END	1.50
7.2 DOCK AND GRAPPLE	2.50
7.3 DISCONNECT CABLE	2.00
7.4 RELEASE AND BACK AWAY	1.00
7.5 MOVE ALONG STRUT AND REMOVE CABLES	5.00
7.6 DISCONNECT OTHER CABLE END	2.00
7.7 MOVE TOWARDS CABLE STOWAGE POSITION	1.50
7.8 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.9 DOCK AND GRAPPLE WITH CABLE CONTAINER	2.50
7.10 STOW CABLE SYSTEM AND ACTIVATE LATCHES	2.00
7.11 RELEASE AND BACK AWAY WITH RMS	1.00
7.12 SELECT ORBITER REF. COORD. SYSTEM	0.25
7.13 MOVE TO SUBSYSTEM MODULE	1.50
7.14 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.15 DOCK AND GRAPPLE SUBSYSTEM MODULE	2.50
7.16 REMOVE SUBSYSTEM MODULE AND BACK AWAY	8.00
7.17 SELECT ORBITER REF. COORD. SYSTEM	0.25
7.18 MOVE TO SUBSYSTEM STOWAGE POSITION	1.50
7.19 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
7.20 DOCK AND GRAPPLE SUBSYSTEM MODULE TO ITS STOWED POSITION	2.50
7.21 ACTIVATE LATCHES & STOW SUBSYSTEM MODULE	0.25
7.22 RELEASE AND BACK AWAY RMS	1.00
TOTAL TIME	39.50
8. REPLACE CHERRY PICKER WITH SPECIAL END EFFECTOR (SEE)	
8.1 SELECT ORBITER REF. COORD. SYSTEM	0.25
8.2 MOVE TO CHERRY PICKER STOWED POSITION	1.50
8.3 DOCK CHERRY PICKER WITH ATTACHED POSITION	10.00
8.4 POWER DOWN CHERRY PICKER AND HAND CONTROL OVER TO AFT FLIGHT DECK FOR RMS RELEASE AND BACK AWAY	1.00
8.5 MOVE TO STOWED SEE POSITION	1.75
8.6 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
8.7 DOCK AND GRAPPLE SEE	2.50
8.8 MAKE ELECTRICAL CONNECTION OF SEE WITH RMS	2.00
8.9 RELEASE SEE RESTRAINT LATCHES AND BACK AWAY	1.00
8.10 CHECK OUT WORKING OF SEE	2.50
TOTAL TIME	32.75

Table 7-15 (Continued)

DESCRIPTION OF OPERATION	TIME (MINUTES)
9. EVA ASTRONAUT REMOVE AND CHECK OUT MMU	
9.1 ASTRONAUT PERFORMS EVA BY MOVING TO MMU AT FLIGHT SUPPORT STATION	2.00
9.2 EVA ASTRONAUT INSTALLS MMU AND STRAPS HIMSELF ON BOARD	5.00
9.3 POWER UP AND PERFORM STATIC CHECK OUT	5.00
9.4 RELEASE MMU FROM FLIGHT SUPPORT STATION	1.00
9.5 PERFORM FLIGHT CHECK OUT WITHIN CARGO BAY	10.00
TOTAL TIME	23.00
10. REMOVE CABLE AND SUBSYSTEM MODULE WITH EVA/MMU AND RMS/SEE	
10.1 SELECT ORBITER REF. COORD. SYSTEM	0.25
10.2 MOVE RMS/SEE TO SUBSYSTEM MODULE	1.50
10.3 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
10.4 DOCK WITH SUBSYSTEM MODULE	2.50
10.5 RELEASE SUBSYSTEM MODULE FROM STRUCTURAL NODE & BACK AWAY	8.00
10.6 SELECT ORBITER REF. COORD. SYSTEM	0.25
10.7 MOVE SEE TO SUBSYSTEM MODULE STOWAGE POSITION	1.50
10.8 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
10.9 DOCK AND STOW SUBSYSTEM MODULE	2.50
10.10 ACTIVATE STOWAGE LATCHES	0.25
10.11 RELEASE RMS AND BACK AWAY	1.00
10.12 MANEUVER MMU TO STRUCTURE MODULE & DOCK	2.50
10.13 EVA DISCONNECT ONE END OF CABLE AND REMOVE CABLE FROM STRUCTURE	5.00
10.14 MANEUVER MMU TO STORAGE CONTAINER AND DOCK	2.50
10.15 STOW CABLE INTO CONTAINER AND ACTIVATE LATCHES	1.00
10.16 RELEASE AND BACK AWAY	1.00
TOTAL TIME	30.25
11. EXPERIMENT BREAKDOWN AND RESTOW	
11.1 MOVE MMU TO APEX OF STRUCTURE MODULE AND DOCK	2.50
11.2 BREAK CENTER HINGE OF TOP STRUT AND FOLD UP TOP TWO STRUCTURE MODES	3.00
11.3 MOVE MMU TO BOTTOM PLANE TO STRUCTURE MODULES AND DOCK	2.50
11.4 BREAK 10 CENTER HINGES ON BOTTOM STRUTS AND FOLD UP STRUCTURE MODULE AND SECURE RESTRAINT LATCHES	20.00
11.5 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
11.6 DOCK AND GRAPPLE STRUCTURE MODULE	2.50
11.7 RELEASE STRUCTURE MODULE FROM CONSTRUCTION HOLDING FIXTURE AND BACK AWAY	1.00

Table 7-15. (Concl.)

DESCRIPTION OF OPERATION	TIME (MINUTES)
11.8 SELECT ORBITER REF. COORD. SYSTEM	0.25
11.9 MOVE RMS AND EVA ASTRONAUT TO STOWAGE CONTAINER	2.50
11.10 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
11.11 DOCK AND STOW STRUCTURE MODULE INTO CONTAINER	2.50
11.12 CLOSE CONTAINER LID AND SECURE LATCHES	1.00
11.13 MOVE MMU TO FLIGHT SUPPORT STATION	1.50
11.14 DOCK MMU AND SECURE	2.00
11.15 POWER DOWN, EVA ASTRONAUT RELEASE SELF-CONSTRAINTS & MOVE TO AIRLOCK	5.00
TOTAL TIME	46.75
12. CONSTRUCTION HOLDING FIXTURE (HAPA) AND RMS SHUTDOWN	
12.1 RETRACT HAPA TO STOWED POSITION	1.00
12.2 POWER DOWN HAPA	2.00
12.3 SECURE HAPA FOR ENTRY AND CHECK OUT	2.50
12.4 REMOVE HAPA SOFTWARE FROM GPC	0.50
12.5 RETRACT RMS TO SEE POSITION	1.50
12.6 SELECT END EFFECTOR REF. COORD. SYSTEM	0.25
12.7 DOCK AND STOW SEE	2.50
12.8 SECURE SEE LATCHES FOR ENTRY	0.50
12.9 RELEASE AND BACK AWAY	1.00
12.10 SELECT AUTO PROGRAM TO MOVE RMS ARM TO PRE-STOW	0.25
12.11 MONITOR AUTO ARM MOVEMENT TO PRE-STOW	0.50
12.12 SELECT DIRECT RMS ARM DRIVE	0.25
12.13 STOW RMS ARM IN RESTRAINTS	2.00
12.14 PERFORM POST-OPERATIONS RMS STATUS CHECKS	5.00
12.15 SHUT DOWN RMS, HEATER, POWER, LIGHTS, CCTV	0.50
TOTAL TIME	20.25

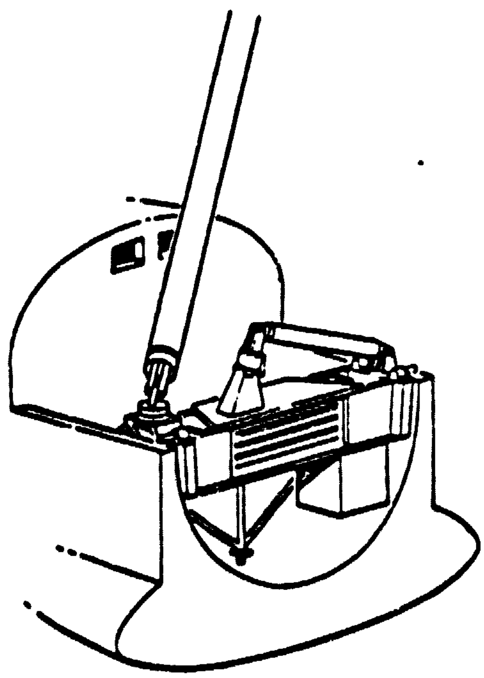


Figure 7-59. Experiment No. 3 Stowed Inside Orbiter Cargo Bay

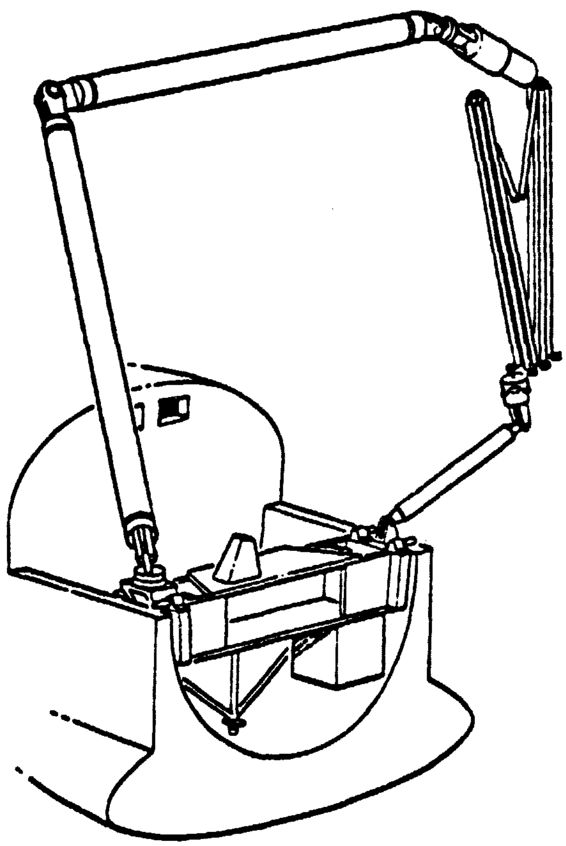


Figure 7-60. Structure Attached to HAPA and Partially Deployed

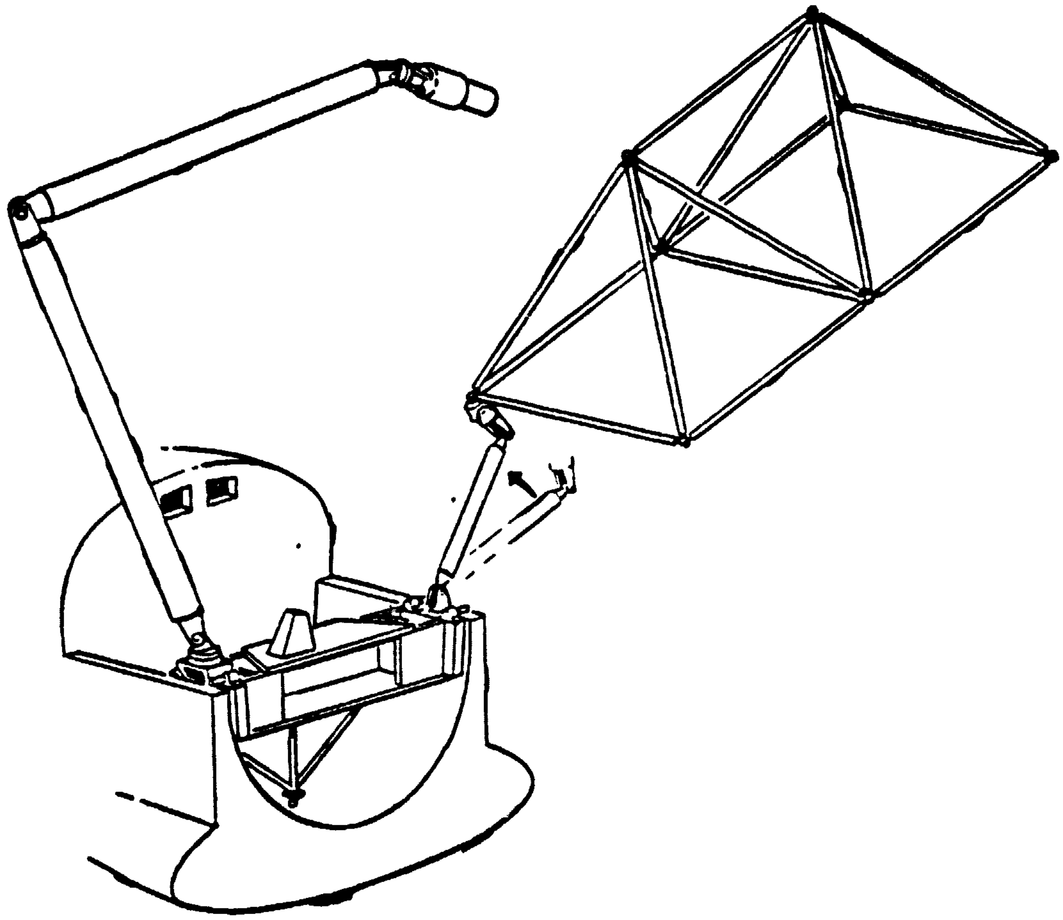


Figure 7-61. HAPA Repositioning the Structure Module

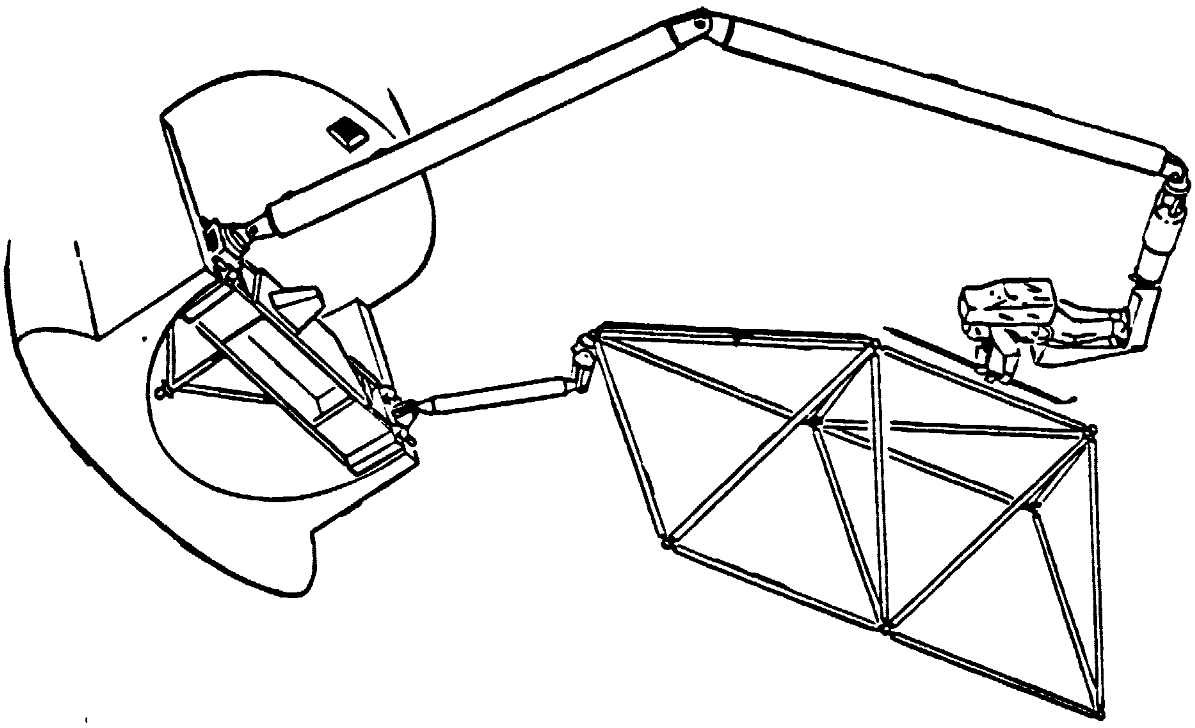


Figure 7-62. Installation of Power/Signal Lines

connected to a junction box on the structure module adjacent to the HAPA docking interface. The connection will be made with the EVA astronaut aboard the cherry picker platform. The RMS moves to other end of duct and moves the duct to Union No. 2 where the structural interface is made to secure the power duct to the structure. The RMS and cherry picker move to the container and remove the coiled power cables and return to Union No. 2. One cable end is connected to the power duct by the EVA astronaut using the probe-type end fitting. The circuit continuity across the connection is checked out to verify successful power connection. The RMS plays out the cable along the strut and attaches the cable at several discrete points along this strut. Another connection is made with a second cable along another strut to the top apex of the structure module. This second cable is played out by the EVA astronaut.

The duct and cable installation experiment are repeated with the orbiter in an attitude hold mode. The first installation was with the orbiter in a free-drift attitude without any external disturbances from the orbiter's vernier RCS thrusters. The repeat installation will show the effects that thruster firing have on this type of construction operation. A mission time line will be recorded for each segment of the mission to understand the relative work-disturbance relationship. The task time has been estimated to require about 71 minutes.

TASK 6 will use the cherry picker and the EVA astronaut to install a simulated subsystem module. The cherry picker is used to transport EVA astronaut to the subsystem module stowed in the cargo bay. The HAPA is moved to position and reorientates the structure for easy installation of the subsystem module to the top farthest node (Figure 7-63). After the module has been installed, the structural and electrical connections are both verified (Figure 7-63). This installation procedure is first attempted with the orbiter in a free-drift mode and afterwards repeated with the orbiter in an inertial attitude hold and a different attitude reorientation. Total time shown for this phase of the mission is 41 minutes.

TASK 7 uses the cherry picker/EVA astronaut combination to remove the subsystem module and the power/signal cables (Figure 7-63) and restow them in their containers.

The cherry picker is moved to the forward station of the cargo bay, docked to its stowage station, and released from the end of the RMS. The RMS and effector are supplemented with a special end effector (SEE) for tests in evaluating the SEE performance with respect to typical space construction activities. The changeover from the cherry picker to the SEE (*TASK 8* should be accomplished in about 32 minutes.

The EVA astronaut will be required to outfit himself with his manned maneuvering unit (MMU) and check out its functional operations (*TASK 9*). This checkout is performed within the cargo bay and has a time of 23 minutes allocated for the operation.

TASK 10 will determine the work effectiveness of the EVA astronaut with the MMU and the RMS/SEE working in combination to perform various space

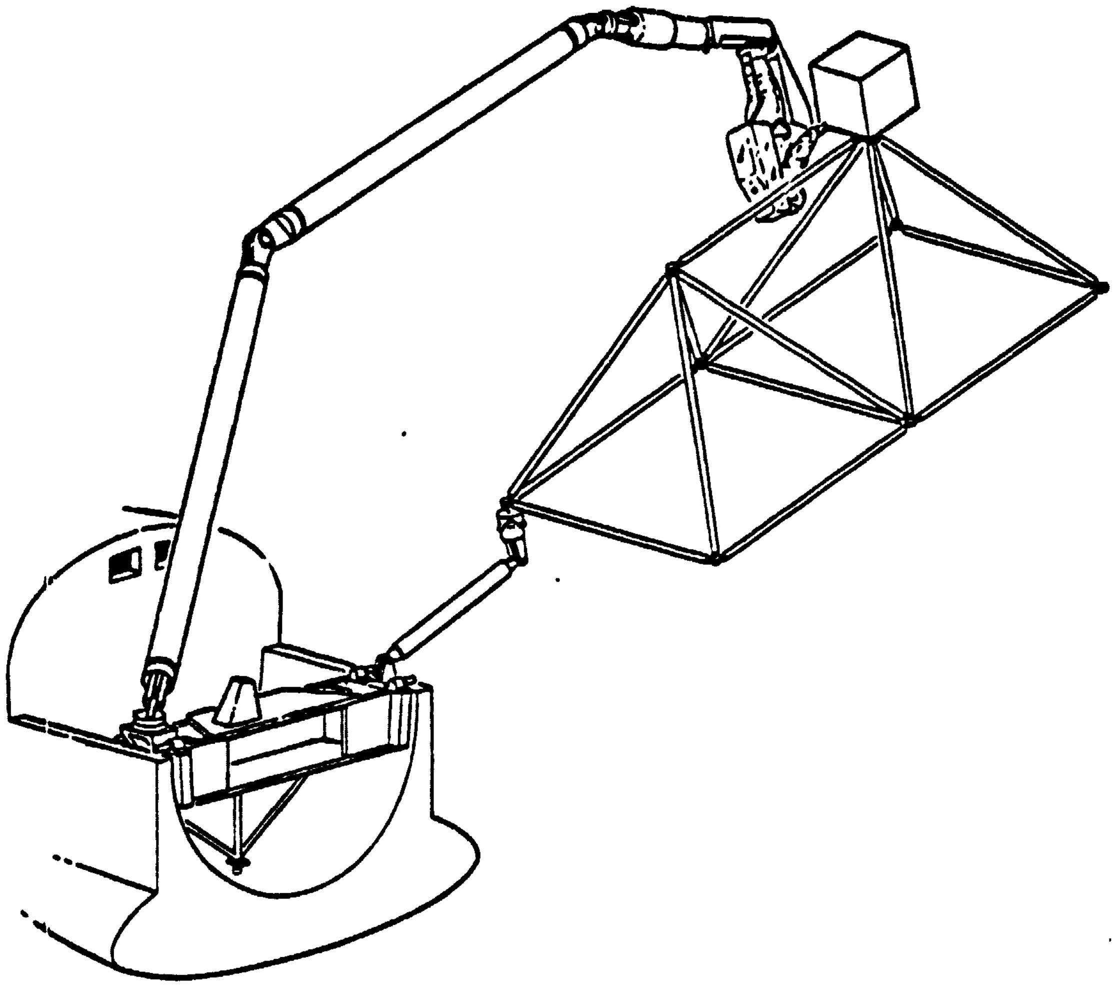


Figure 7-63. Cherry Picker Installing Equipment Module

operations such as installing, removing, and stowing the subsystem module and power/signal cables and ducts. The container and tie-down latches will be activated. The task time has been estimated to be about one-half an hour.

TASK 11 will be the experiment breakdown of the structure module and stowage of the HAPA. Initially the center hinges are unlocked using the longards attached to the structure, and these longards are reeled in to retract the overall structure. After the struts are bundled together, the restraining fittings are attached to the nodes, the structure module released from the docking interface, and restowed into their containers. The astro-worker takes the MMU to the forward docking station in the cargo bay. He docks and secures the MMU, then powers down the MMU, releases the self-constraints, and ends his EVA by entering the air lock. Time required for this task has been assessed to be about 46.75 minutes.

TASK 12, the final task, is to stow and power-down the RMS and the handling and positioning device.

It has been estimated that the overall mission time line for Experiment No. 3 is 7-1/2 hours (Table 7-16).

Table 7-16. Summary of Mission Timeline for Experiment 3

	SUMMARY DESCRIPTION OF OPERATIONS	TIME (MIN)
1.	PREPARING RMS FOR OPERATION	24.00
2.	PREPARING HAPA FOR OPERATION	24.25
3.	ATTACH AND PREPARE CHERRY PICKER FOR OPERATION	26.00
4.	RELEASE AND DEPLOY STRUT MODULE	67.00
5.	INSTALL CABLES AND MAKE CORRECTION	71.00
6.	EVA/CHERRY PICKER INSTALL SUBSYSTEM MODULE	41.00
7.	REMOVE CABLES AND SUBSYSTEM MODULE	39.50
8.	REPLACE CHERRY PICKER WITH SPEE	32.75
9.	EVA CREWMAN REMOVE AND CHECK OUT MMU	23.00
10.	INSTALL CABLE AND SUBSYSTEM MODULE WITH EVA/MMU AND RMS/SPEE	31.25
11.	EXPERIMENT—BREAKDOWN AND RESTOW	44.25
12.	HAPA AND RMS SHUTDOWN	20.25
	TOTAL TIME	444.25 (7.4 HR)

7.3.3 Experiment No. 3/Orbiter Interface

Orbiter support for and interface with the Construction Equipment Effectiveness experiment (Experiment 3) is discussed in this section. The general arrangement of the orbiter interface review is the same as that used for Experiment No. 2 and Experiment 2 (Prime)—see Sections 7.1.4 and 7.2.3. The two interface areas of experiment components and experiment operations are summarized in Table 7-17. The emphasis in Experiment No. 3 is on the evaluation of space construction equipment for performing typical large space system construction tasks.

The construction aids include the (1) standard RMS, (2) the RMS with a special end effector (SEE), (3) holding and positioning aid (HAPA), (4) the EVA and cherry picker[1] combination, and (5) EVA and MMU combination. The tasks to be compared include items such as (1) removing the deployable structure (two cells of a typical LSS platform) from its packaged position and enlarging to its deployed position, (2) installing utility line segments into the test structure and power/data interface connections, (3) installing test versions of platform payload modules onto the deployed structure, (4) removing, refolding, and restoring the experiment components back into the experiment container in readiness for the orbiter return flight, and (5) evaluating the capability of the HAPA to hold and maneuver the experiment structure during the various experiment operations.

The Experiment No. 3 component interfaces with the orbiter systems are generally similar to those discussed earlier for Experiments 2 and 2 (Prime). The two components not discussed earlier are the HAPA and the cherry picker. Further comments about these two items follow.

Holding and Positioning Aid (HAPA)

The HAPA performance is to be evaluated in the proposed Experiment No. 3 for its effectiveness in assisting in LSS platform deployment operations and in maintaining and/or maneuvering the deployed structure during the installation of systems. The HAPA will be installed on the experiment container and the container structure. These will, in turn, be attached to the payload bay structure in such a manner so as to react the experiment operations loads as well as the orbiter flight loads. The HAPA design concepts include built-in deployment mechanisms and the active half of a berthing device. The HAPA, therefore, requires interface connections with the orbiter electrical power and power control systems.

The deployment of the HAPA will be performed from the AFD console, so additional interface connections will be required with the avionics displays and controls located at the console. Experiment instrumentation will be installed on the HAPA structure in order to measure and monitor loading on the HAPA structural members during packaged structure attached to the HAPA,

[1]Cherry picker is also referred to as "Manned Remote Work Station (MRWS)" in other NASA/industry reports.

Table 7-17. Experiment No. 3/Orbiter Interface Matrix

EXPERIMENT COMPONENTS AND OPERATIONS	SELECTED ORBITER SYSTEMS AND SUBSYSTEMS			AVIONICS														
	PAYLOAD BAY STRUCTURE	PAYLOAD BAY PALLET	ORBITER RMS	COMM. AND TRACKING	DISPLAYS AND CONTROLS	CAUTION AND WARNING	DATA PROC. & SOFTWARE	ELEC. POWER DIST. & CONTR.	ELECTRICAL POWER	PAYLOAD BAY LIGHTING	CLOSED-CIRCUIT TV (CCTV)	AFT FLIGHT DECK CONSOLE	AFT FLIGHT DECK CREW	EVA CREW	MANNED MANEUVERING UNIT	CHERRY PICKER	REACTION CONTR. SYSTEM (RCS)	P/L GROUND HANDLING SYS.
COMPONENTS																		
1. DEPLOYABLE STRUCTURE		X					X	X	X			X						
2. EXPERIMENT CONTAINER	X	X						X	X			X						X
3. CONTAINER SUPPORT	X	X			X	X						X						
4. EQUIPMENT MODULE	X	X			X	X	X	X	X	X		X						
5. UMBIL., WIRE HARNESS, ETC		X																
6. HAND. & POS. AID (HAPA)	X	X			X		X	X	X			X						
7. RMS	X		–		X	X	X	X	X		X	X						
8. SPEC. END EFFECTOR (SEE)		X			X		X	X	X			X						
9. MANNED MANEUV. UNIT (MMU)	X	X																
10. CHERRY PICKER	X	X	X									X						
OPERATIONS																		
1. PREPARE RMS FOR OPERA.			X		X		X	X	X		X	X	X					
2. PREPARE HAPA FOR OPERATION		X			X		X	X	X			X	X					
3. ATTACH & PREPARE CHERRY PICKER FOR OP.	X	X	X						X	X	X	X	X	X		X		
4. RELEASE AND DEPLOY STRUCTURE MODULE		X	X		X	X	X	X	X	X	X	X	X					
5. INSTALL CABLES AND MAKE CONNECTIONS		X	X		X	X	X	X	X	X	X	X	X	TBD		TBD	X	
6. INSTALL SUBSYST. MODULE WITH EVA/CHERRY PICKER		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
7. REMOVE CABLES & S/S MOD.		X	X		X	X	X	X	X	X	X	X	X	TBD		TBD		
8. REPLACE CH.PKR. WITH SEE		X	X					X	X	X	X	X	X	TBD		TBD		
9. EVA CREW REMOVE & CHECK OUT MMU		X								X	X	X	X	X	X			
10. REMOVE CABLE & S/S MOD WITH EVA/MMU & RMS/SEE		X	X	X	X	X	X	X	X	X	X	X	X	X	X			
11. BREAK DOWN & RESTOW EXPMT		X	X		X	X	X	X	X	X		X	X	X	X			
12. SHUT DOWN HAPA AND RMS			X		X		X	X	X			X	X					

during deployment of the structure and during the other test operations. The data processing and software system will therefore require an interface with the HAPA as well as with the other experiment components having data measurement requirements.

Cherry Picker

The cherry picker unit will provide a desirable method of EVA astronaut mobility in and around the payload bay. The mobility will be limited by the reach and accessibility constraints of the RMS. A measure of such limitations will be a major purpose of the cherry picker testing phase of Experiment No. 3.

The cherry picker interface with the orbiter requires installation of the cherry picker stowage rack in the payload bay for the launch and descent parts of the mission. Combining this interface with the experiment container structure may be possible. The major cherry picker interface will be with the RMS. Here, the cherry picker will replace or be fastened to the RMS end effector. RMS control handover and operations monitoring and override will be monitored from the AFD console. Therefore, the appropriate control interface must be installed.

Operations

The operations involved in Experiment No. 3 are described in detail in the Mission Scenario section (7.3.2). The major orbiter interfaces during these operations are indicated in Table 7-17. Items shown as "TBD" are areas that are to be determined after further detailed studies and ground tests. They generally involve decisions on whether or not EVA skills will be required to complete certain test operations, or whether EVA alternatives for automated operations also should be tested during the Experiment No. 3 flight.

The preliminary weight estimate of the test equipment and flight support equipment (Table 7-18) shows that the cargo manifest will be 2020 lb. Table 7-19 shows that the total energy required is 22,491 kJ, and the average power is 0.04 kW.

Table 7-18. Cargo Manifest—Experiment No. 3

TEST ARTICLE (220 LB)

	STRUTS
10	HINGES
36	BALL ENDS
8	UNIONS
1	BERTHING ADAPTER
	WIRING
1	BERTHING J-BOX
10	SPRINGS/DAMPERS

EQUIPMENT MODULE (50 LB)

STRUCTURE
J-BOX

HANDLING & POSITIONING AID (50 LB)

1	ARM
2	HINGES
1	BERTHING ADAPTER
1	BERTHING J-BOX
1	DEPLOYMENT ACTUATOR
1	STRUCTURE SUPPORT

CRADLE ASSEMBLY (200 LB)

1	CRADLE
1	BERTHING MOUNT
3	ATTACHMENT TRUNNIONS

SUPPORT EQUIPMENT (1550 LB)

1	CHERRY PICKER	350
1	MMU	300
2	EVA SUITS	350
1	FSS	50
3	EVA	500

TOTAL WEIGHT—2020 LB

Table 7-19. Mission Power Allocation - Experiment 3

		TIME (MIN.)	AVG. PWR (kW)	ENERGY (kJ)
1.	RMS	24.0	0.845	1,217
	RMS WRIST LITE	8.0	0.173	83
	AFT CREW STA. LITE	8.0	0.200	96
	WRIST TV & HTR.	24.0	0.023	33
	ELBOW TV & HTR.	24.0	0.057	82
2.	HAPA HEATERS	20.75	.845	1,052
	AFT CREW STA. LITE	6.9	0.200	83
	THREE CARGO BAY LITES	6.9	0.600	83
3.	RMS	16.0	0.845	811
	RMS WRIST LITE	5.0	0.173	54
	AFT CREW STA. LITE	8.67	0.200	104
	THREE CARGO BAY LITES	8.67	0.600	312
	FWD TV CAMERA & HTR.	8.67	0.057	30
	AFT TV CAMERA & HTR.	5.0	0.057	17
	ELBOW TV CAMERA	15.0	0.057	51
4.	RMS	67.0	0.845	3,397
	RMS WRIST LITE	13.4	0.173	139
	AFT CREW STA. LITE	22.3	0.200	267
	THREE CARGO BAY LITES	22.3	0.600	802
	FWD TV CAMERA & HTR.	33.5	0.057	114
	AFT TV CAMERA & HTR.	33.5	0.057	114
	ELBOW CAMERA & HTR.	33.5	0.057	114
	WRIST TV CAMERA	33.5	0.023	46
5.	RMS	48.0	0.845	2,433
	RMS WRIST LITE	16.0	0.173	166
	AFT CREW STA. LITE	16.0	0.200	192
	THREE CARGO BAY LITES	16.0	0.600	576
	FWD TV CAMERA & HTR.	16.0	0.057	54
	ELBOW CAMERA & HTR.	48.0	0.057	164
	WRIST TV CAMERA	16.0	0.023	22
6.	RMS	41.00	0.845	2,078
	RMS WRIST LITE	13.7	0.173	142
	AFT CREW STA. LITE	13.7	0.200	164
	THREE CARGO BAY LITES	13.7	0.600	493
	FWD TV CAMERA & HTR.	13.7	0.057	46
	ELBOW CAMERA & HTR.	41.0	0.057	140
	WRIST TV CAMERA	13.7	0.023	19
7.	RMS	39.5	0.845	2,003
	RMS WRIST LITE	13.2	0.173	137
	AFT CREW STA. LITE	13.2	0.200	158
	THREE CARGO BAY LITES	13.2	0.600	475
	FWD TV CAMERA & HTR.	26.3	0.057	90
	ELBOW CAMERA & HTR.	39.5	0.057	135
	WRIST TV CAMERA	13.2	0.023	18

Table 7-19. Mission Power Allocation - Experiment 3

	TIME (MIN.)	AVG. PWR (kW)	ENERGY (kJ)
8. RMS	32.75	0.845	1.660
RMS WRIST LITE	11.0	0.173	114
AFT CREW STA. LITE	11.0	0.200	132
THREE CARGO BAY LITES	11.0	0.600	396
FWD TV CAMERA & HTR	22.0	0.057	75
ELBOW CAMERA & HTR	32.75	0.057	112
WRIST TV CAMERA	11.0	0.023	15
9. MMU	16.0	0.600	576
AFT CREW STA. LITE	7.7	0.200	92
THREE CARGO BAY LITES	7.7	0.600	277
FWD TV CAMERA & HTR.	23.0	0.057	78
AFT TV CAMERA & HTR.	23.0	0.057	78
TOTAL TASK 3 KJ =			22,491

7.4 EXPERIMENT NO. 3 (PRIME) - CONSTRUCTION EXPERIMENT EFFECTIVENESS EXPERIMENT VARIATION

This experiment is a low cost version and limited test objectives version of Experiment No. 3. The main differences are that there will not be a cherry picker and the holding and positioning aid is replaced with a single arm from the PIDA.

7.4.1 Configuration Description

Experiment No. 3 (Prime), as shown in Figure 7-64 , suggests a test structure of low fidelity as a facility to perform basic space construction tasks such as deployment of a holding fixture, attachment of the structure to the fixture, EVA attachment of hardware with RMS cooperation, and EVA and RMS installation of equipment modules and electrical cables. The experiment does not require a cherry picker or MMU. In place of a special holding fixture, the PIDA was substituted which is assumed to be operational at the time of the experiment. Similarly, the two-cell structure of Experiment No. 3 was replaced by a single cell structure.

The stowage of Experiment No. 3 (Prime) is shown in Figure 7-64 It presents a different stowage approach to illustrate the flexibility with which Experiment No. 3 and Experiment No. 3 (Prime) can be treated. Figure 7-64 shows that the packaging of Experiment No. 3 (Prime) can be accommodated with a Spacelab and its associated tunnel and airlock.

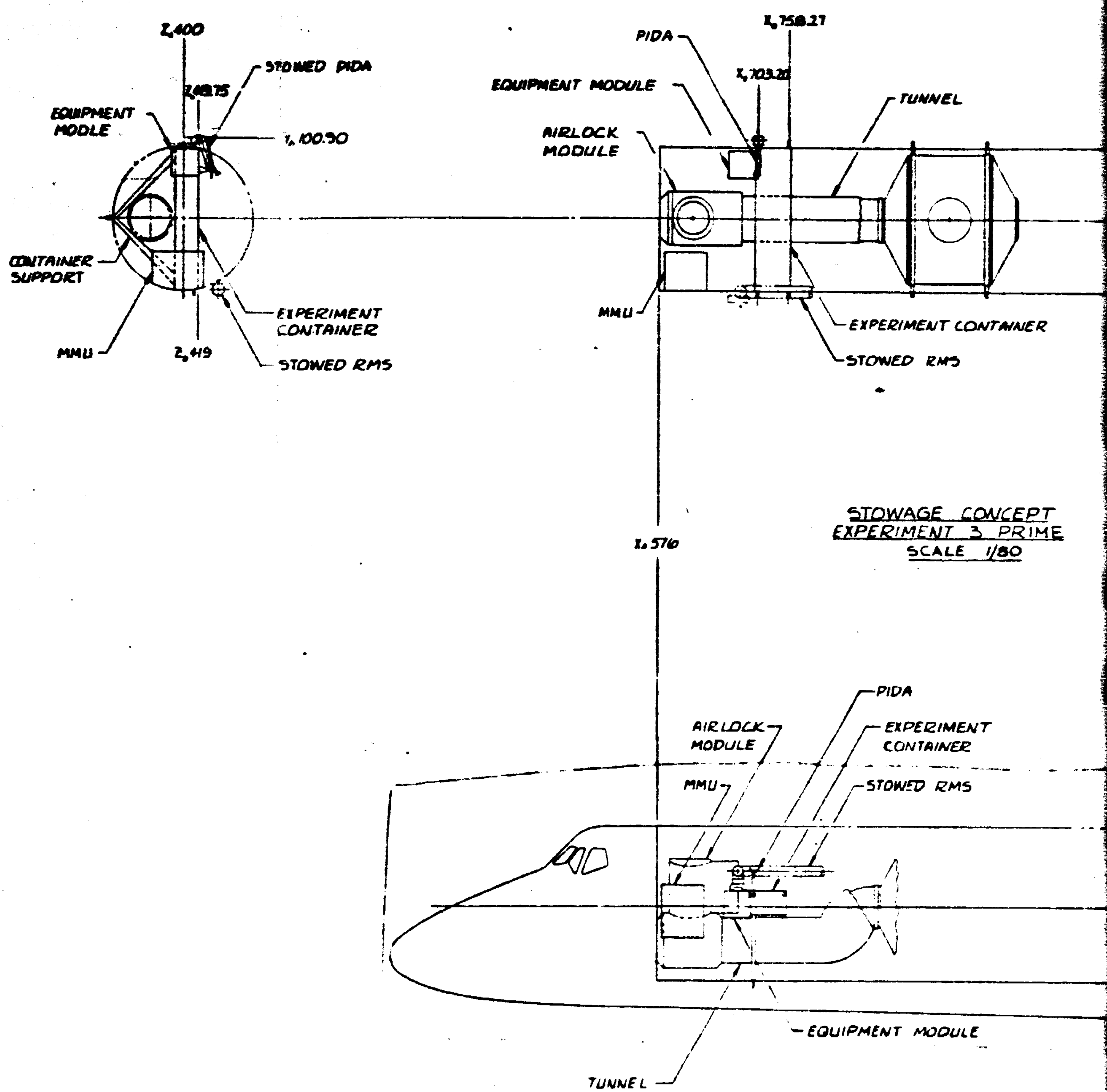
7.4.2 Mission Scenario

The mission scenario (Figure 7-65) will be similar to the scenario laid out for Experiment No. 3, but without the cherry picker and MMU operations. A mission timeline for each operation is indicated in Table 7-20. Tasks 1 and 2 are concerned with preparing the RMS and the PIDA for operations by releasing power-up and checkout. The estimated times for these two tasks are 24 and 18 minutes, respectively.

The RMS will release, and attach the structure module to a PIDA interface and release the restraint fitting to allow full deployment of the single cell test structure. After deployment, each hinge is checked to ensure that it is fully locked. Time taken for this task has been estimated to be 27.25 minutes.

Installation of the power/signal lines with their connections and the subsystem module to the structural node are performed using the RMS end effector. Both of these tasks are repeated with the orbiter performing attitude hold maneuvering and reorientation to determine the effects of thrust disturbences of the operational procedures. Time for Task 4, installation of cables, is less than 52 minutes while Task 5, subsystem (equipment) module installation, takes only 31 minutes.

The power/signal lines and subsystem module are removed and restowed into their containers; time taken is 37.5 minutes.



STOWAGE CONCEPT
EXPERIMENT 3 PRIME
SCALE 1/80

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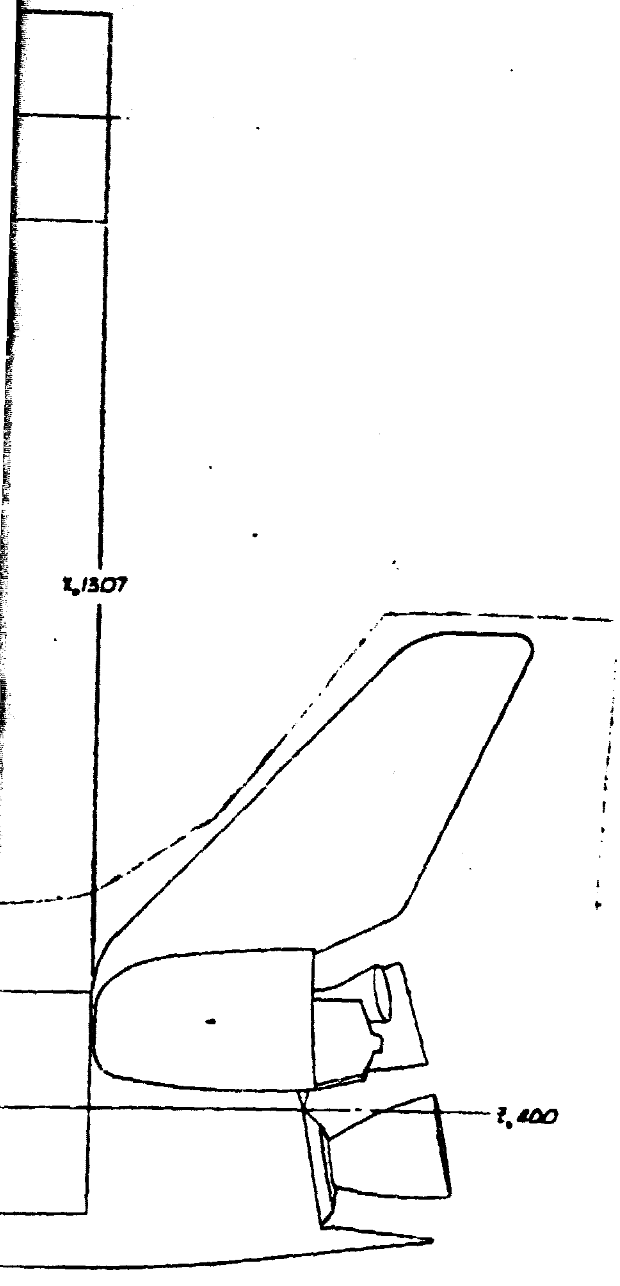

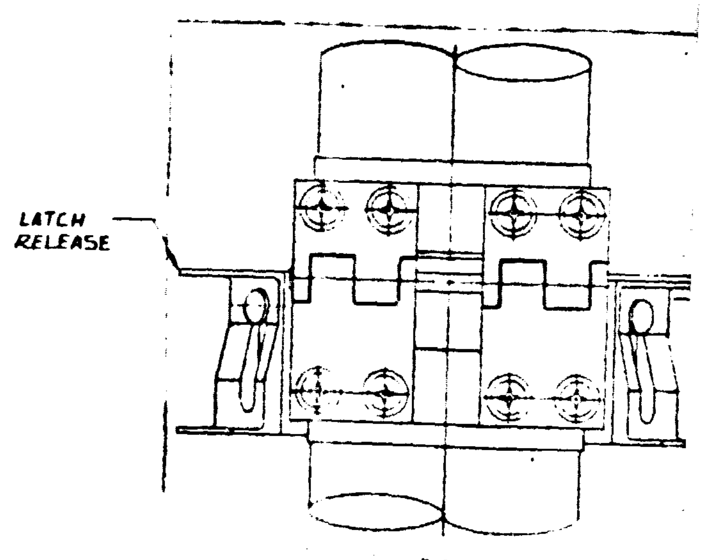

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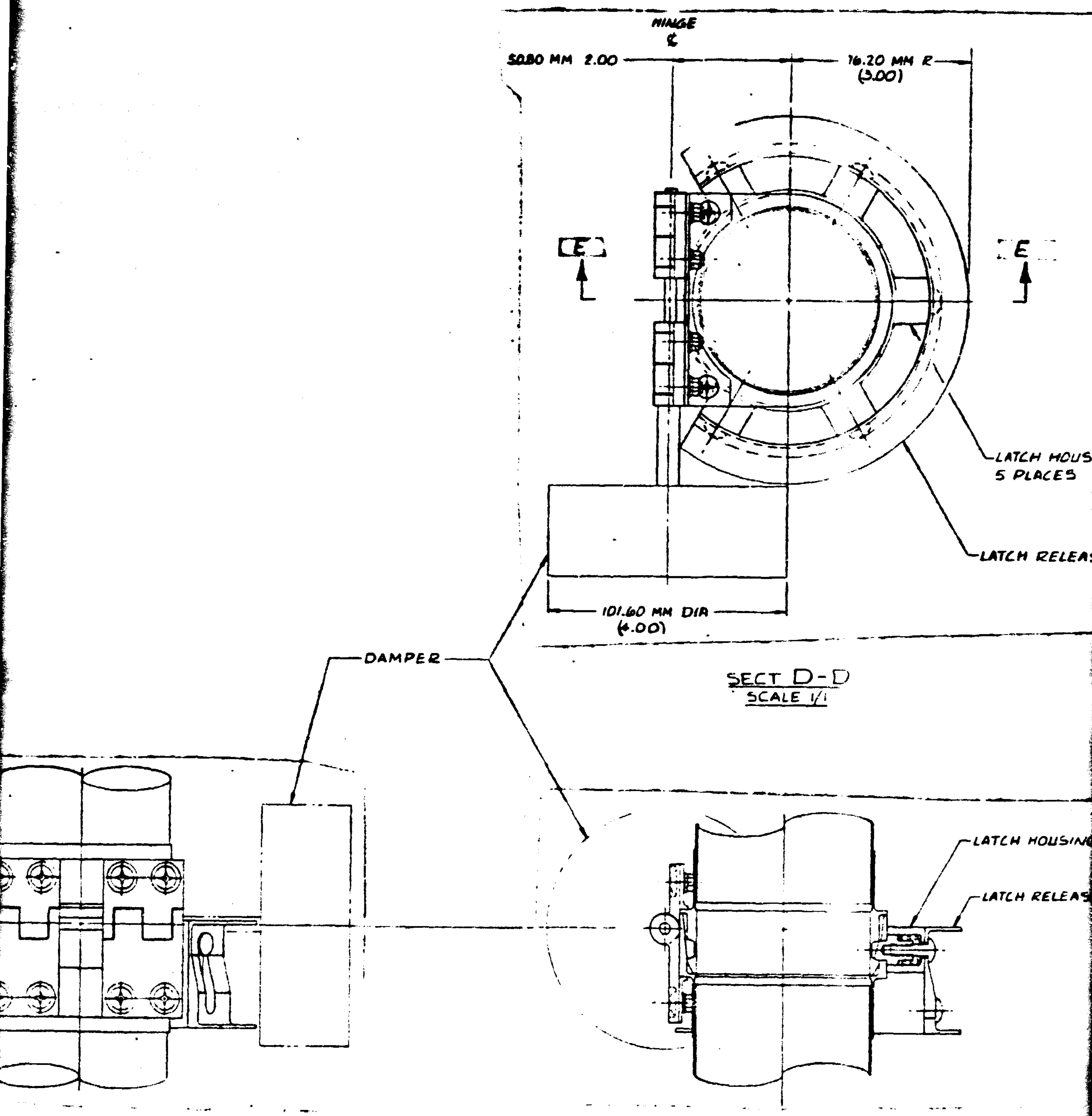
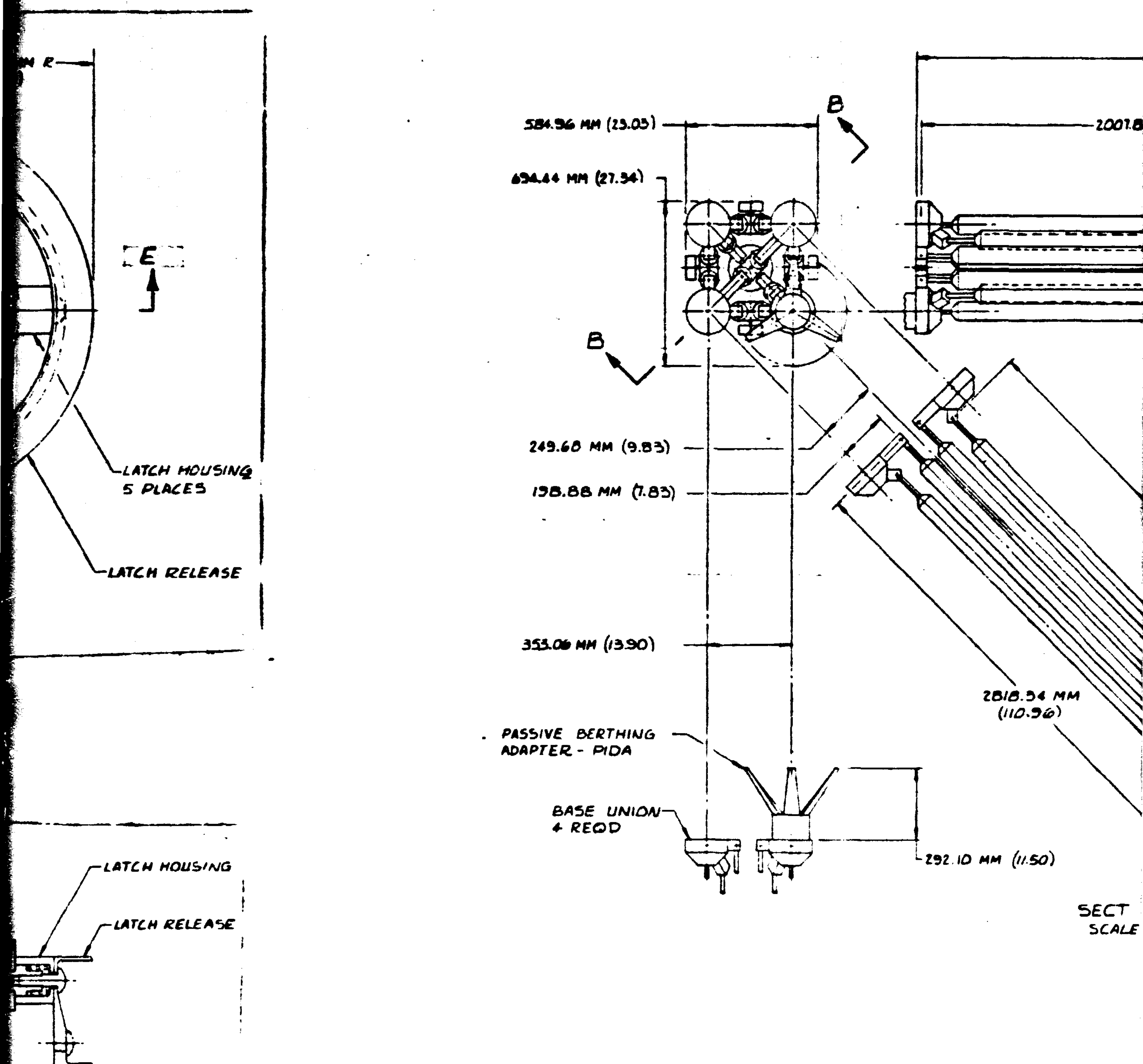


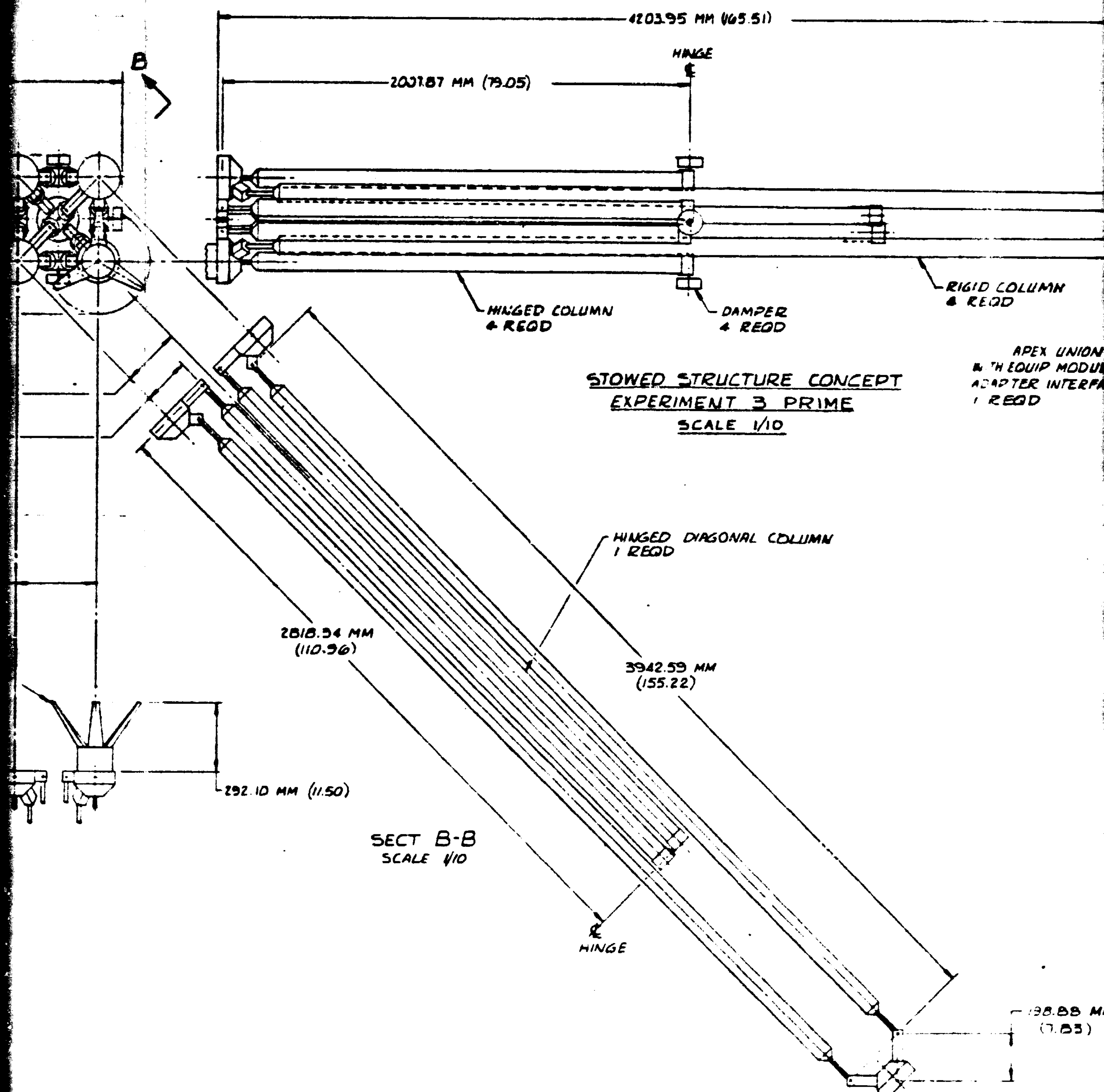
SECT D-D
SCALE 1/1

SECT E-E
SCALE 1/1

3 FOLDOUT FRAME



4 FOLDOUT FRAME



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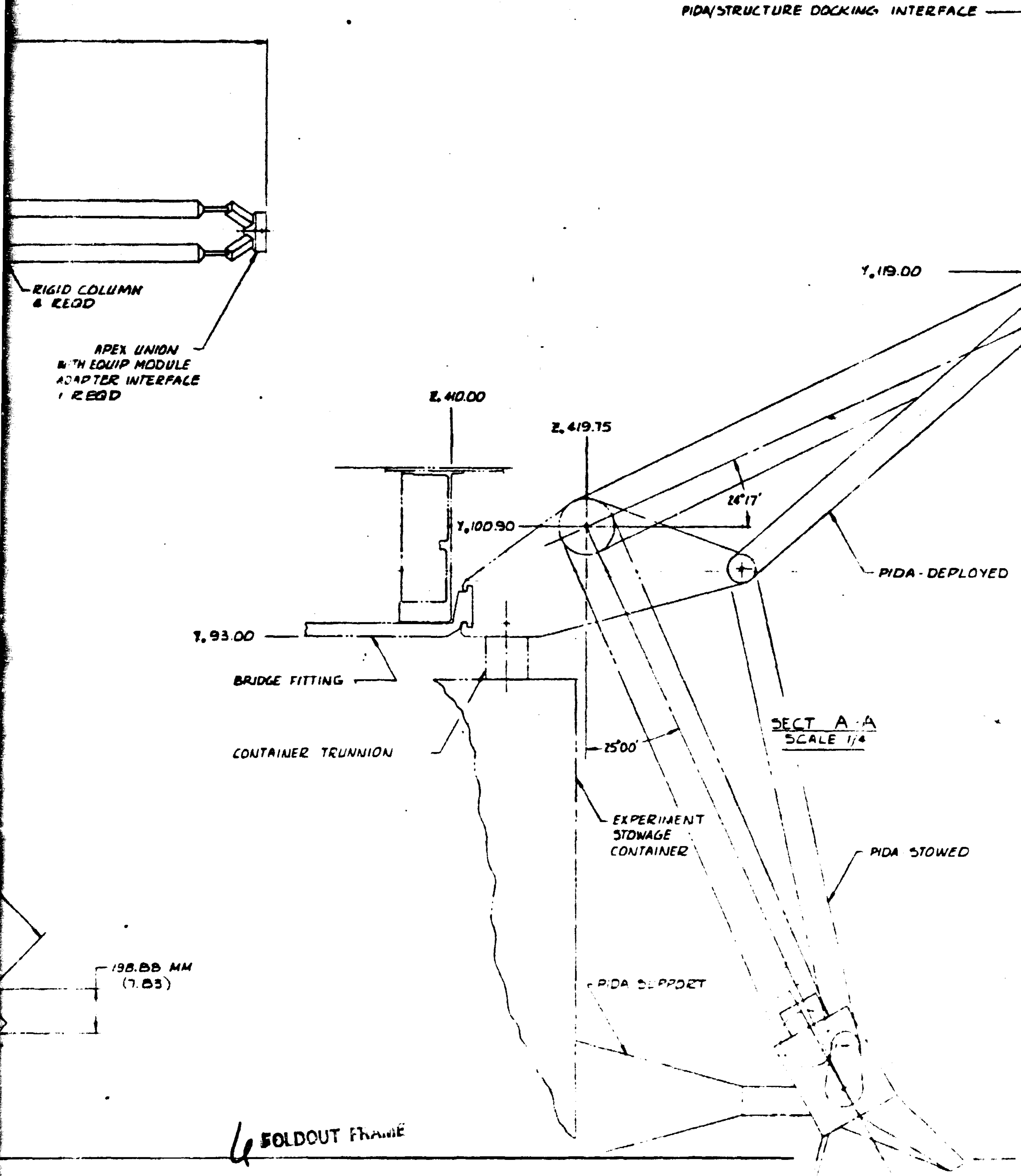

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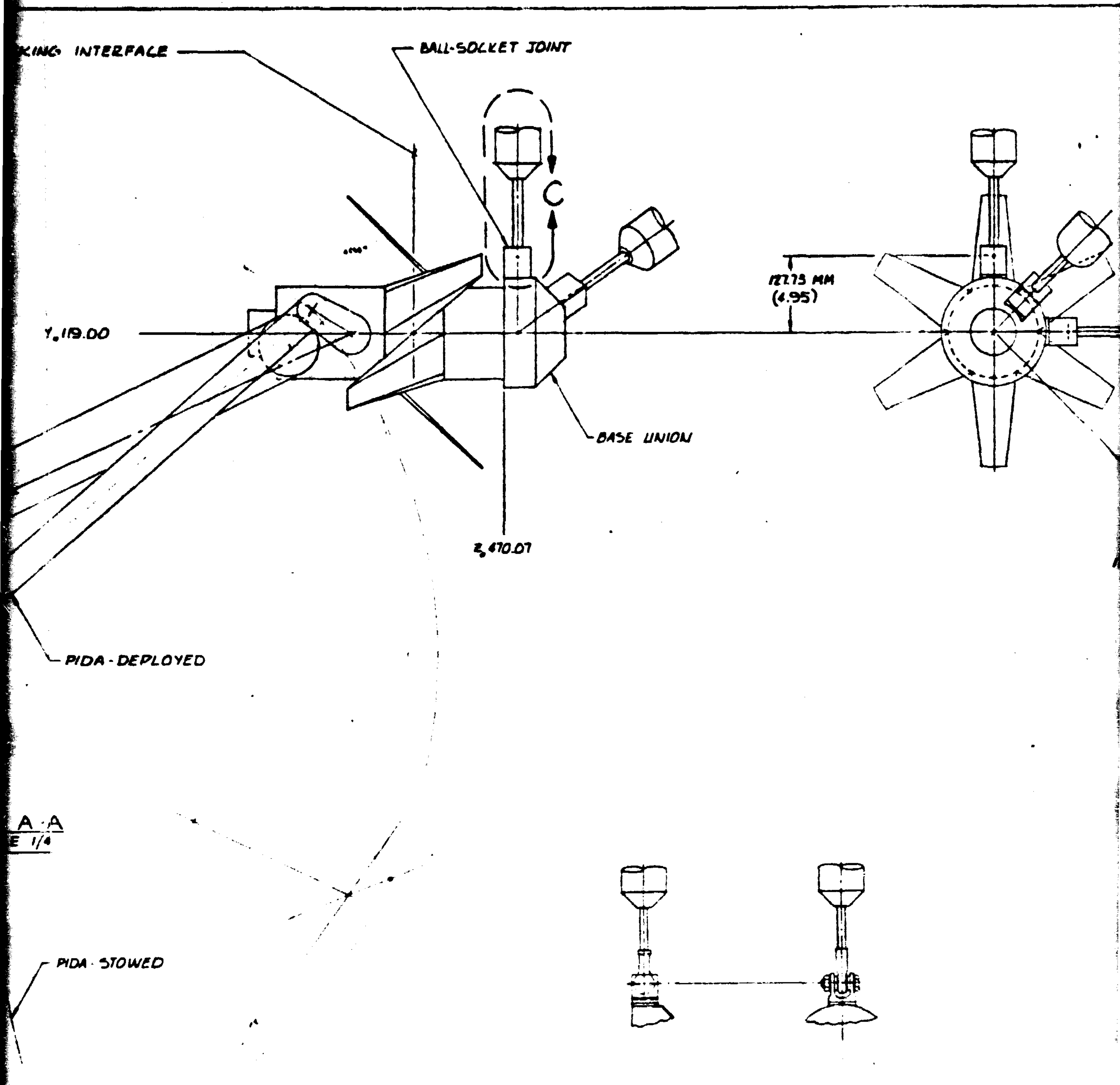
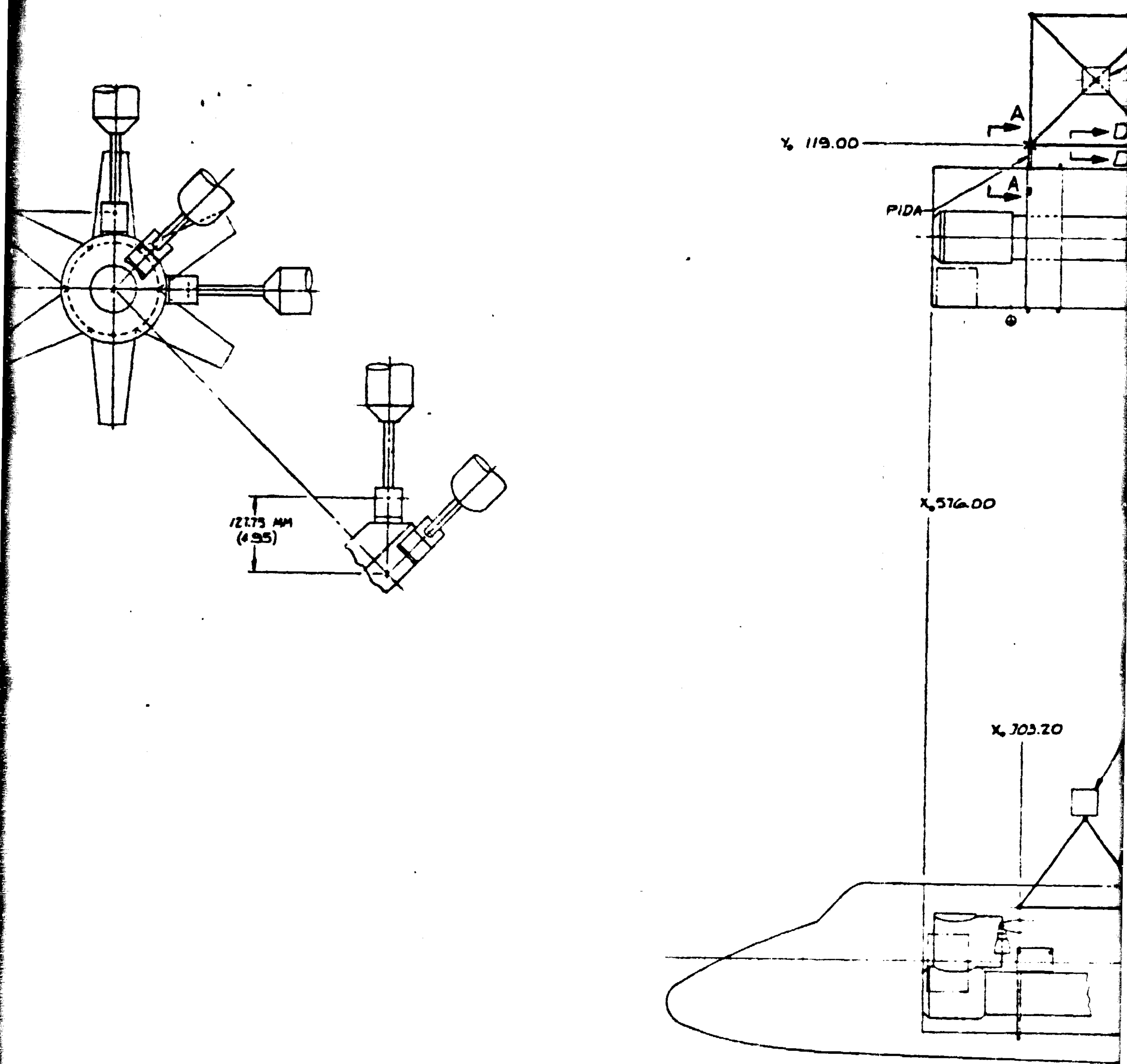


DETAIL C
ALTERNATE JOINT DESIGN
SCALE 1/4

1



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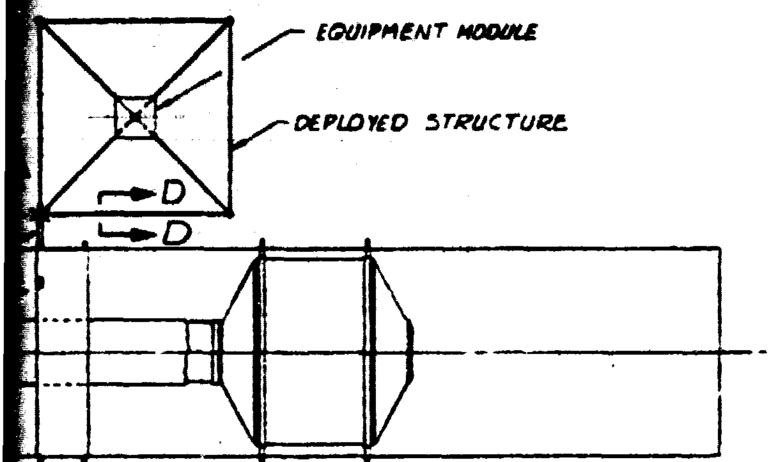
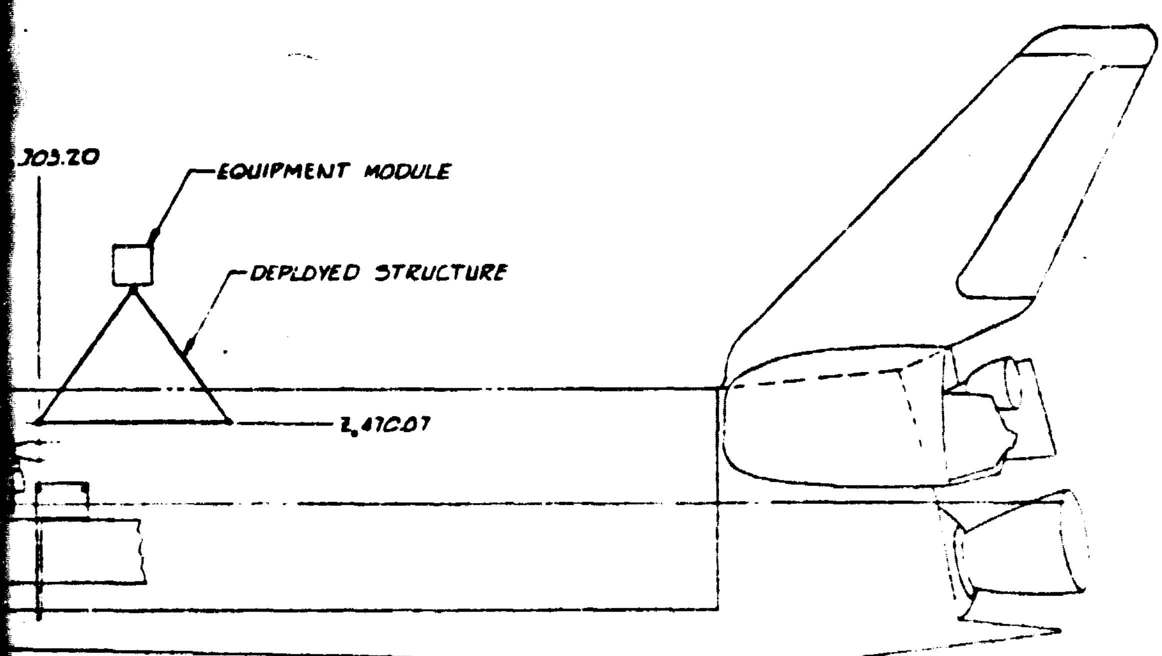


DEPLOYED EXPERIMENT
3 PRIME
SCALE 1/80



9 FOLDOUT FRAME

FLIGH
DEPL

10 FOLDOUT FRAME

REV 2.18BO RST

Figure 7-64.

NOTES		ROCKWELL INTERNATIONAL CORPORATION SPACE DIVISION	
FLIGHT EXPERIMENT NO 3 PRIME DEPLOYED & STOWED CONFIG			226602-77

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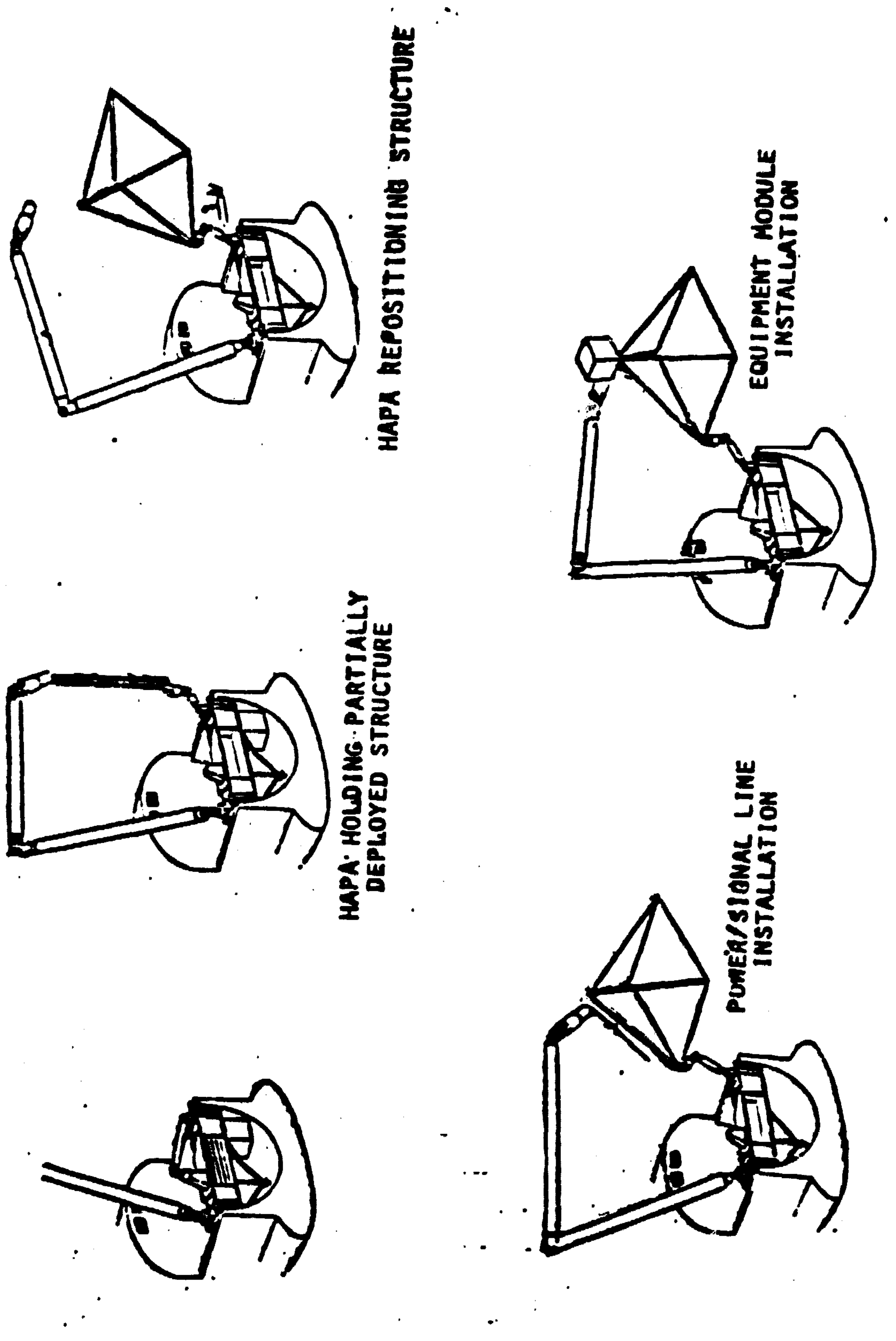

Figure 7-65. Mission Operational Sequence

Table 7-20. Time Estimates for Nine Operational Tasks in Mission Scenario

1. PREPARING RMS FOR OPERATION

SHEET 1 OF 7

DESCRIPTION OF OPERATION		TIME (MIN.)
1.1	PREPARE GPCs FOR RMS OPERATION	3.5
1.2	MANEUVER TO DEPLOYMENT ATTITUDE	6.5
1.3	POWER UP MANIPULATOR ARM HEATERS	(6.5)
1.4	POWER UP, CHECK OUT CCTV/LIGHTS	(5.0)
1.5	POWER UP MANIPULATOR - UNLOCK HAND CONTROLLERS	(1.0)
1.6	STABILIZE - FREE DRIFT - RCS OFF	(1.0)
1.7	PERFORM MANIPULATOR ARM STATIC CHECKOUT	5.0
1.8	ROTATE MANIPULATOR ARM - RELEASE RESTRAINTS	2.0
1.9	SELECT AUTO PROGRAM - DEPLOY MANIP.ARM	1.5
1.10	PERFORM MANIP. FUNCTIONAL CHECKS	5.0
1.11	SELECT/VERIFY MANUAL AUG. CONTROL	0.25
	TOTAL TIME LAPSED	24 MINS

2. PREPARE PIDA FOR OPERATION

DESCRIPTION OF OPERATION		TIME (MINUTES)
2.1	PREPARE GPCs FOR PIDA OPERATION	3.5
2.2	POWER UP PIDA—UNLOCK HAND CONTROLLERS	1.0
2.3	PERFORM PIDA STATIC CHECKOUT	5.0
2.4	RELEASE RESTRAINTS	0.25
2.5	SELECT AUTO PROGRAM—DEPLOY PIDA	3.0
2.6	PERFORM PIDA FUNCTIONAL CHECKS	5.0
2.7	SELECT/VERIFY MANUAL CONTROL	0.25
	TOTAL TIME LAPSED	18.00

3. RELEASE AND DEPLOY STRUCTURES MODULE

	DESCRIPTION OF OPERATION	TIME (MIN.)
3.1	MOVE END EFFECTOR TO LID OF STRUCTURE CONTAINER—CRADLE BOX	1.50
3.2	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
3.3	DOCK END EFFECTOR WITH ATTACHMENT POINT ON LID & GRAPPLE	2.50
3.4	RELEASE CONTAINER LID HOLD-DOWN LATCHES	0.25
3.5	MOVE END EFFECTOR TO OPEN CONTAINER LID	1.50
3.6	RELEASE CONTAINER LID	1.00
3.7	SELECT ORBITER REFERENCE COORD. SYSTEM	0.25
3.8	M/A MODE MOVE END EFFECTOR TO STOWED STRUCTURE	1.50
3.9	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
3.10	DOCK END EFFECTOR TO GRAPPLE FIXTURE ON STOWED STRUCTURE	2.50
3.11	RELEASE CONTAINER LATCHES AND RESTRAINING CLAMPS AROUND STRUCTURE	0.25
3.12	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.13	WITHDRAW FOLDED STRUCTURE FROM INSIDE CONTAINER BOX	1.50
3.14	MOVE FOLDED STRUCTURE TO STARBOARD SIDE OF CARGO BAY	1.50
3.15	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
3.16	ROTATE FOLDED STRUCTURE TO VERTICAL POSITION	0.50
3.17	DOCK FOLDED STRUCTURE WITH PIDA AND LOCK	2.50
3.18	RELEASE GRAPPLE FIXTURE AND BACK RMS AWAY	0.25
3.19	MOVE END EFFECTOR TO GRAPPLE FITTING OF UNION RESTRAINTS	0.50
3.20	DOCK WITH GRAPPLE FITTING USED FOR RESTRAINING BASE UNIONS	2.50
3.21	RELEASE UNION RESTRAINTS AND BACK RMS AWAY	1.00
3.22	ALLOW STRUCTURE TO DEPLOY AND CENTER HINGES TO LOCK	2.00
3.23	SELECT ORBITER REF. COORD. SYSTEM	0.25
3.24	MOVE TO CENTER HINGE NO. 1	1.50
3.25	ASSURE HINGE NO. 1 IS LOCKED	1.00
3.26	REPEAT STEPS 3.24 AND 3.25 FOR HINGES NO. 2 THROUGH NO. 5	10.00
	TOTAL TIME	37.25

4. INSTALL CABLES AND MAKE CONNECTIONS

DESCRIPTION OF OPERATION	TIME (MIN.)
4.1 SELECT ORBITER REFERENCE COORD. SYSTEM	0.25
4.2 MOVE END EFFECTOR TO CABLE CONTAINER	1.50
4.3 SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
4.4 DOCK AND GRAPPLE WITH CABLE CONTAINER	2.50
4.5 RELEASE CABLE CONTAINER RESTRAINT LATCHES	0.25
4.6 REMOVE CABLE FROM CONTAINER	1.00
4.7 SELECT ORBITER REFERENCE COORD. SYSTEM	0.25
4.8 MOVE PIDA	1.50
4.9 SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
4.10 DOCK AT PIDA	2.50
4.11 MAKE ELECTRICAL CONNECTION	1.00
4.12 MOVE ALONG STRUTS, PLAY OUT CABLE & ATTACH TO COLUMNS LEADING TO EQUIPMENT MODULE	5.00
4.13 MAKE ELECTRICAL CONNECTION	1.00
4.14-4.26 REMOVE CABLES AND REPEAT ABOVE OPERATIONS UNDER ATTITUDE HOLD CONDITION WITH ORBITER	17.25
4.27-4.39 REMOVE CABLE AND REPEAT ABOVE OPERATIONS UNDER ATTITUDE REORIENTATION	17.25
TOTAL TIME	51.75

5. INSTALL SYSTEM (EQUIPMENT) MODULE

DESCRIPTION OF OPERATION	TIME (MIN.)
5.1 SELECT ORBIT REFERENCE COORD. SYSTEM	0.25
5.2 MOVE END EFFECTOR TO STOWED POSITION OF SUBSYSTEM MODULE	1.50
5.3 SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
5.4 DOCK AND GRAPPLE WITH SUBSYSTEM MODULE	2.50
5.5 RELEASE SUBSYSTEM MODULE RESTRAINT LATCHES AND REMOVE	1.25
5.6 TRANSPORT SUBSYSTEM MODULE TO APEX UNION	1.50
5.7 SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
5.8 DOCK SUBSYSTEM MODULE TO APEX UNION	2:50
5.9 INSTALL SUBSYSTEM MODULE AND CHECK OUT	3.00
5.10 REMOVE SUBSYSTEM MODULE AND BACK AWAY	6.00
5.11 REPEAT STEPS 5.9 AND 5.10 OPERATIONS UNDER ATTITUDE HOLD	9.00
5.12 REPEAT STEP 5.9 FOR ATTITUDE REORIENTATION	3.00
TOTAL TIME	31.00

6. REMOVE CABLES AND SUBSYSTEM MODULE

DESCRIPTION OF OPERATIONS		TIME (MIN.)
6.1	MOVE END EFFECTOR TO SUBSYSTEM MODULE END OF CABLE	1.50
6.2	DOCK AND GRAPPLE	2.50
6.3	DISCONNECT CABLE	2.00
6.4	RELEASE AND BACK AWAY	1.00
6.5	MOVE ALONG STRUCTURE & REMOVE CABLES	5.00
6.6	DISCONNECT PIDA CABLE END	2.00
6.7	MOVE TOWARD CABLE STOWAGE POSITION	1.50
6.8	SELECT END EFFECTOR-REFERENCE COORD. SYSTEM	0.25
6.9	DOCK AND GRAPPLE WITH CABLE CONTAINER	2.50
6.10	STOW CABLE SYSTEM AND ACTIVATE LATCHES	2.00
6.11	RELEASE AND BACK RMS AWAY	1.00
6.12	SELECT ORBITER REFERENCE COORD. SYSTEM	0.25
6.13	MOVE TO SUBSYSTEM MODULE	1.50
6.14	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
6.15	DOCK AND GRAPPLE SUBSYSTEM MODULE	2.50
6.16	REMOVE SUBSYSTEM MODULE AND BACK AWAY	6.00
6.17	SELECT ORBITER REFERENCE COORD. SYSTEM	0.25
6.18	MOVE TO SUBSYSTEM STOWAGE POSITION	1.50
6.19	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
6.20	DOCK AND GRAPPLE SUBSYSTEM MODULE TO ITS STOWED POSITION	2.50
6.21	ACTIVATE LATCHES AND STOW SUBSYSTEM MODULE	0.25
6.22	RELEASE AND BACK RMS AWAY	1.00
	TOTAL TIME	37.50

7. EVA CREWMAN REMOVE AND CHECK OUT MMU

DESCRIPTION OF OPERATION		TIME (MIN.)
7.1	ASTRONAUT PERFORMS EVA BY MOVING TO MMU AT FLIGHT SUPPORT STATION	2.00
7.2	EVA ASTRONAUT INSTALLS MMU AND STRAPS HIMSELF ON BOARD	5.00
7.3	POWER UP AND PERFORM STATIC CHECKOUT	5.00
7.4	RELEASE MMU FROM FLIGHT SUPPORT STATION	1.00
7.5	PERFORM FLIGHT CHECKOUT WITHIN CARGO BAY	10.00
	TOTAL TIME	23.00

8. EXPERIMENT BREAKDOWN AND RESTOW

DESCRIPTION OF OPERATION		TIME (MIN.)
8.1	MOVE MMU TO HINGE NO. 1	2.00
8.2	UNLATCH HINGE NO. 1	0.50
8.3	REPEAT STEPS 8.1 & 8.2 FOR HINGES NO. 2 THROUGH NO. 5	10.00
8.4	MOVE MMU TO APEX UNION	2.00
8.5	ACTIVATE REFOLD MECHANISM	1.00
8.6	ALLOW STRUCTURE TO REFOLD	2.00
8.7	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
8.8	MOVE END EFFECTOR TO STRUCTURE GRAPPLE FIXTURE	1.50
8.9	DOCK AND GRAPPLE STRUCTURE	2.50
8.10	RELEASE STRUCTURE FROM PIDA	1.00
8.11	SELECT ORBITER REFERENCE COORD. SYSTEM	0.25
8.12	MOVE RMS AND EVA ASTRONAUT TO STOWAGE CONTAINER	2.50
8.13	SELECT END EFFECTOR REFERENCE COORD. SYSTEM	0.25
8.14	DOCK AND STOW STRUT MODULE INTO CONTAINER	2.50
8.15	CLOSE CONTAINER LID AND SECURE LATCHES	1.00
8.16	MOVE MMU TO FLIGHT SUPPORT STATION	1.50
8.17	DOCK MMU AND SECURE	2.00
8.18	POWER DOWN, EVA ASTRONAUT RELEASE SELF-CONSTRAINTS AND MOVE TO AIRLOCK	5.00
	TOTAL TIME	37.75

9. PIDA AND RMS SHUTDOWN

	DESCRIPTION OF OPERATION	TIME (MIN.)
9.1	RETRACT PIDA TO STOWED POSITION	1.00
9.2	POWER DOWN PIDA	2.00
9.3	SECURE PIDA FOR ENTRY AND CHECK OUT	2.50
9.4	REMOVE PIDA SOFTWARE FROM GPC	0.50
9.5	SELECT AUTO PROGRAM TO MOVE RMS ARM TO PRE-STOW	0.25
9.6	MONITOR AUTO ARM MOVEMENT TO PRE-STOW	0.50
9.7	SELECT DIRECT RMS ARM DRIVE	0.25
9.8	STOW RMS-ARM IN RESTRAINTS	2.00
9.9	PERFORM POST-OPERATIONS RMS STATUS CHECKS	5.00
9.10	SHUT DOWN RMS, HEATER, POWER, LIGHTS, CCTV	0.50
	TOTAL TIME	14.50

Task 7 requires the EVA astronaut to strap himself into the MMU, perform the necessary checkouts (time 23 minutes) and then assist the RMS with the breakdown operation of the structure module. The center hinge lock and folding mechanisms of this structure will be attempted by the MMU/EVA astronaut. The RMS will hold the structure and after its release from the PIDA docking interface, will transport the structure module to its container within the orbiter's cargo bay. The astronaut will secure the restraining latches to the experiment equipment and move to the MMU support station, dock, power down and remove the MMU prior to entering the airlock. Time for the breakdown and restowing has been scheduled to be less than 38 minutes. The remaining task in the mission is the PIDA and RMS shutdown and restowage.

Total time for Experiment No. 3 (Prime) mission is about 4½ hours, with the time summary for each task shown in Table 7-21 and Figure 7-66.

7.4.3 Experiment No. 3 Prime/Orbiter Interface

Experiment No. 3 (Prime) provides a somewhat simplified and less expensive version of Experiment No. 3. The major component elimination is the deletion of the cherry picker from the list of experiment items. The test operations for this unit are then eliminated also. The deployable structure is similar to that used in Experiment No. 3 but is reduced in size to only one platform pentahedral cell rather than the two cell structure planned for the previous test.

The smaller structure and consequent reduction in payload moment arm will allow reduction in the design requirements for the HAPA. The handling and positioning aid planned is, therefore, of smaller dimensions and corresponds to a "PIDA" handling device.

Table 7-22 summarizes the major orbiter systems interfaces with the Experiment No. 3 (Prime) components and operations in a manner similar to those shown and discussed for the other three experiment proposals of the study. The individual interface descriptions are similar enough to those already given so they will not be repeated here. Mission planning statements concerning experiment weight, center of gravity, electrical power requirements will need to be developed in the detail study as was planned for the other experiments.

Table 7-21. Summary of Mission Timeline for Experiment 3 (Prime)

SUMMARY DESCRIPTION OF OPERATIONS	TIME (MINUTES)
1. PREPARING RMS FOR OPERATION	24.00
2. PREPARING PIDA FOR OPERATION	18.00
3. RELEASE AND DEPLOY STRUCTURE	37.25
4. INSTALL CABLES AND MAKE CONNECTION	51.75
5. INSTALL SUBSYSTEM MODULE	31.00
6. REMOVE CABLES AND SUBSYSTEM MODULE	37.50
7. EVA CREWMAN REMOVE AND CHECK OUT MMU	23.00
8. EXPERIMENT—BREAK DOWN AND RESTOW	37.75
9. PIDA AND RMS SHUTDOWN	14.50
TOTAL TIME LAPSED	274.75 (4 HR, 34.75 MIN)

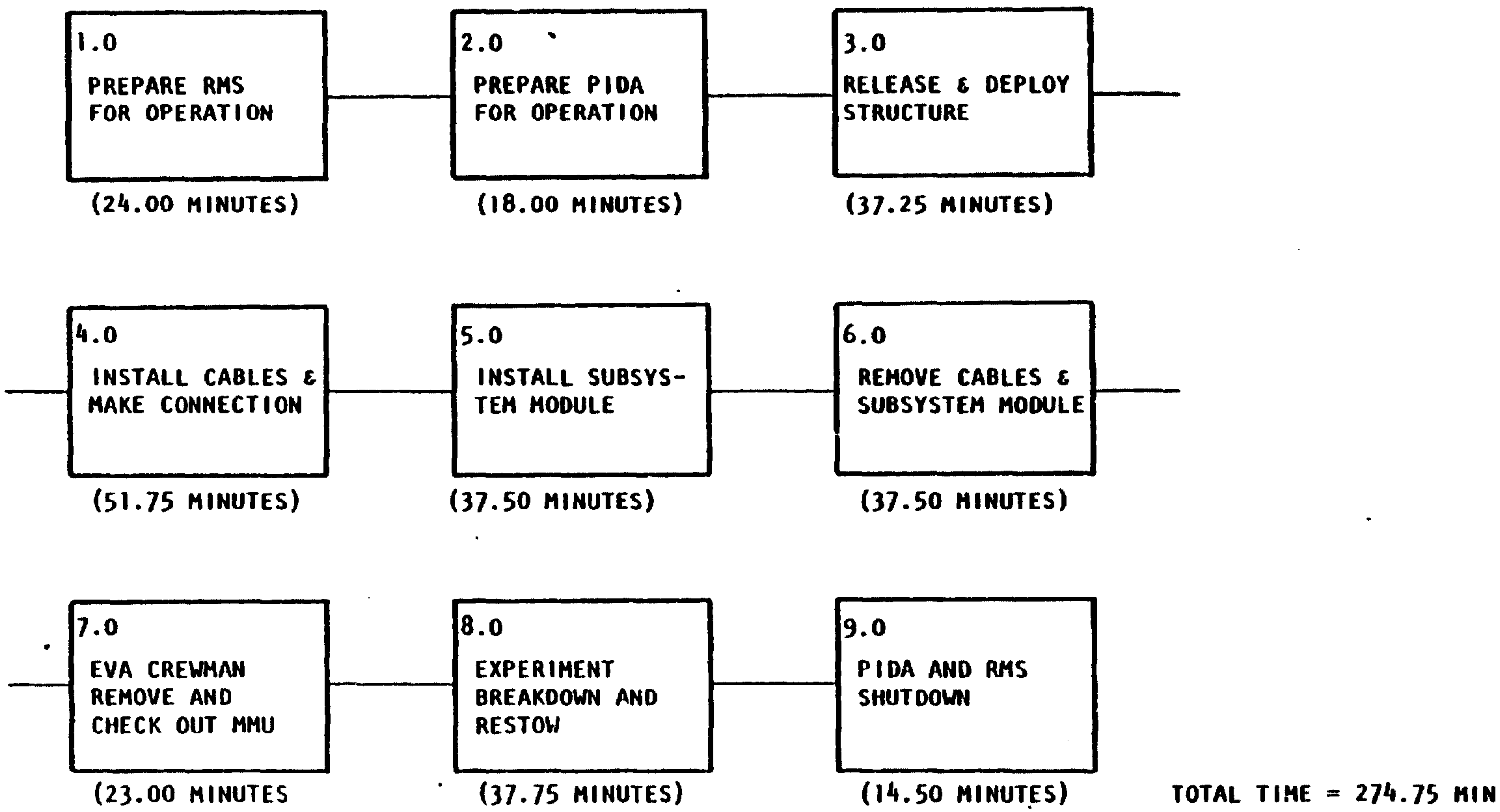

Figure 7-66. Summary to Operational Events for Experiment No. 3—Prime

Table 7-22. Experiment No. 3 (Prime) Orbiter Interface Matrix

EXPERIMENT COMPONENTS AND OPERATIONS	SELECTED ORBITER SYSTEMS AND SUBSYSTEMS			AVIONICS														
	PAYLOAD BAY STRUCTURE	PAYLOAD BAY PALLET	ORBITER RMS	COMM. AND TRACKING	DISPLAYS AND CONTROLS	CAUTION AND WARNING	DATA PROC. & SOFTWARE	ELEC. POWER DIST. & CONTR.	ELECTRICAL POWER	PAYLOAD BAY LIGHTING	CLOSED-CIRCUIT TV (CCTV)	AFT FLIGHT DECK CONSOLE	AFT FLIGHT DECK CREW	EVA CREW	MANNED MANEUVERING UNIT	CHERRY PICKER	REACTION CONTR. SYSTEM (RCS)	P/L GROUND HANDLING SYS.
COMPONENTS																		
1. DEPLOYABLE STRUCTURE		X					X	X	X			X						
2. EXPERIMENT CONTAINER	X	X						X				X						X
3. CONTAINER SUPPORT	X	X			X	X			X	X		X						
4. EQUIPMENT MODULE	X	X			X	X	X	X										
5. UMBIL., WIRE HARNESS, ETC		X	X						X			X						
6. HAND. & POS. AID (HAPA)	X	X			X		X	X	X		X	X						
7. RMS	X		-		X	X	X	X	X			X						
8. SPEC. END EFFECTOR (SEE)		X			X		X	X										
9. MANNED MANEUV. UNIT (MMU)	X	X																
10. CHERRY PICKER																		
OPERATIONS																		
1. PREPARE RMS FOR OPERA.			X		X		X	X	X		X	X	X					
2. PREPARE HAPA (PIDA) FOR OPERATION		X			X		X	X	X			X	X					
3. RELEASE & DEPLOY STRUCTURE MODULE		X	X		X	X	X	X	X	X	X	X	X					
4. INSTALL CABLES & MAKE CONNECTIONS		X	X		X	X	X	X	X	X	X	X	X				X	
5. REMOVE CABLES & SUB-SYSTEM MODULE		X	X		X	X	X	X	X	X	X	X	X					
6. EVA CREW REMOVE & C/O MMU		X								X	X	X	X	X	X			
7. INSTALL SEE ON RMS		X	X					X	X	X	X	X	X	X	X			
8. INSTALL SUBSYST. MODULE & CABLE WITH EVA & RMS/SEE		X	X		X	X	X	X	X	X	X	X	X	X	X			
9. REMOVE CABLE & SUBSYST. MOD WITH EVA & RMS/SEE		X	X		X	X	X	X	X	X	X	X	X	X	X			
10. BREAK DOWN AND RESTOW EXPERIMENT		X	X		X	X	X	X	X	X		X	X	X	X			
11. SHUT DOWN HAPA AND RMS			X		X		X	X	X			X	X					

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APPENDIX

PRECISION DEPLOYABLE BOOM EXPERIMENT

APPENDIX

PRECISION DEPLOYABLE BOOM EXPERIMENT

INTRODUCTION

This appendix presents the results of analysis and definition tasks for a Precision Deployable Boom Experiment completed at the close of the Space Construction Experiments Concepts Study. The Space Construction Flight Experiments program is summarized to introduce the precision deployable boom experiment in its proper perspective. The experiment is summarized with an advanced controls technology emphasis.

FLIGHT EXPERIMENT PROGRAMS

The Space Construction System Flight Experiment program is composed of five orbiter flight experiments as shown in Figure A-1.

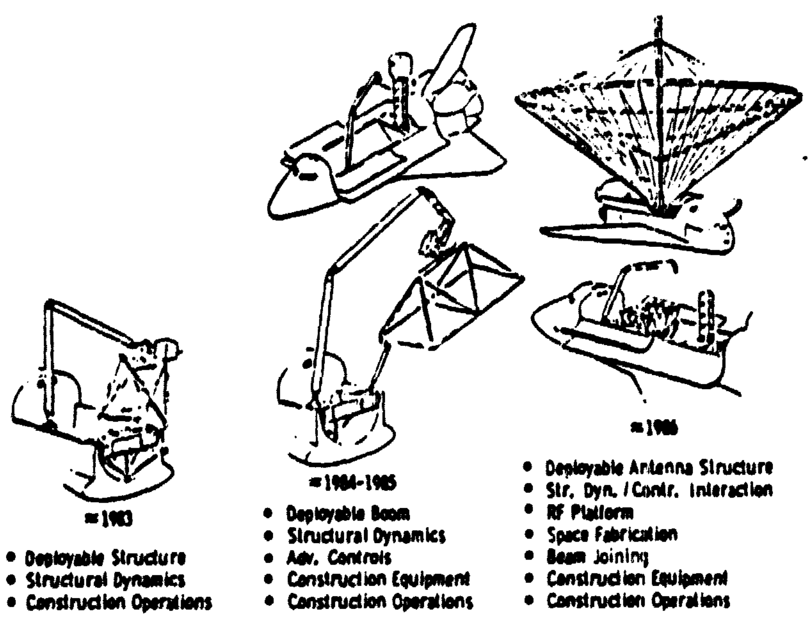


Figure A-1. Flight Experiment Program

The three experiments along the lower portion of the figure are those required to support large space platform construction technology development. They are, respectively, (1) the Deployed/Assembled Structural Dynamics Experiment, (2) the Construction Equipment Effectiveness Experiment, and (3) the Space Fabrication/Assembly Experiment.

The remaining two experiments—the Precision Deployable Boom Experiment and the Large Antenna Experiment—are involved in furthering large antenna and advanced control technology for large space platform payloads. The precision deployable boom experiment is a precursor to the large antenna experiment since the boom would be a prototype for the antenna feed structure and would verify advanced control techniques for shaping/damping control for large space antennas, as well as orbiter autopilot pointing and stability.

All five flight experiments have considerable commonality as related to construction and assembly tasks requiring the orbiter remote manipulator system (RMS) and the tasks performed, assisted, or monitored by the EVA astronauts.

The paragraphs that follow expand and provide definition and depth for the deployable boom experiment that would fly in the 1984-1985 time period.

EXPERIMENT OBJECTIVES

The precision deployable boom experiment can capture many important flight experiment objectives as they relate to large (100 m to 300 m) antenna feed masts. Referring to Figure A-2, a large simulated antenna feed installation can be demonstrated using the RMS. As a 100-m mast is deployed, EVA-assisted deployment of feed cabling may be demonstrated. In conjunction with this deployment shaping, control actuators and electrical connections may be installed by an EVA astronaut.

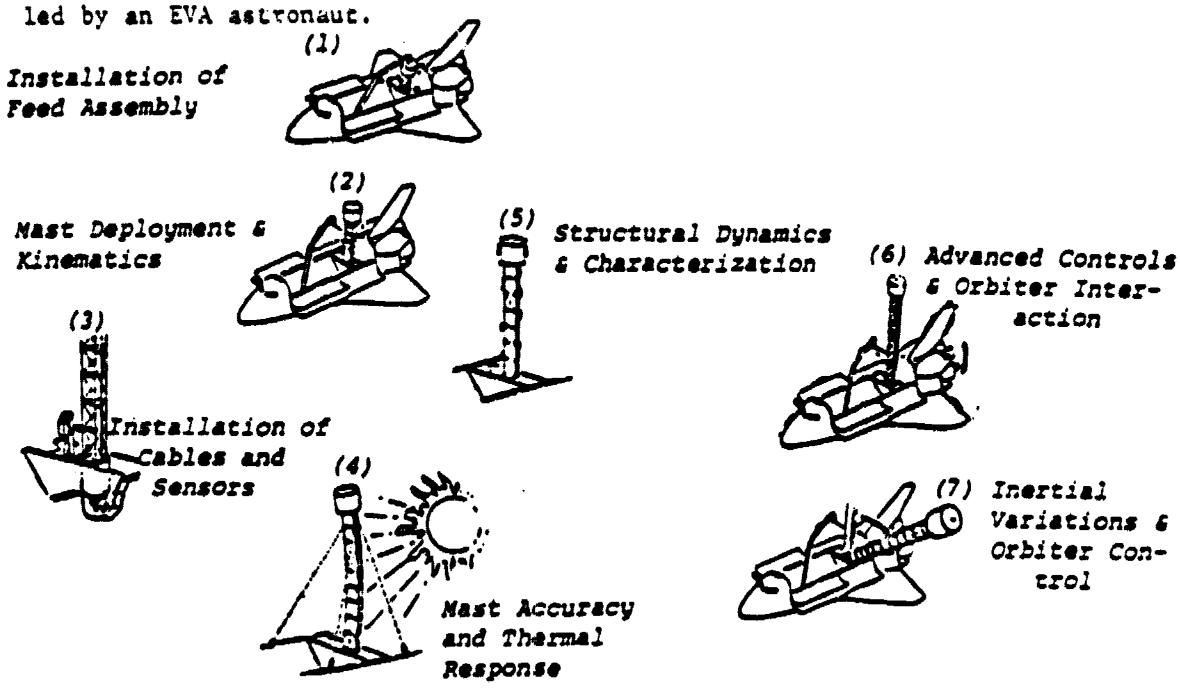


Figure A-2. Precision Deployable Boom Experiment

Orbiter perturbations may be analyzed as to interaction with construction tasks and mast dynamics under attitude-hold and free-drift modes. Mast alignment and thermal distortion can be evaluated.

Advanced control techniques can be evaluated with active shaping control of actuators installed appropriately along the mast. The mast could be excited at specified structural frequencies. By tilting the mast along the Y-Z plane with a 2000-kg mass on the end of the mast, the control authority of the RCS/orbiter autopilot can be evaluated, simulating large space construction interaction effects.

The precision boom, because of its length and the control authority it can exercise over the orbiter, is a versatile simulator of large space construction effects—particularly as related to orbiter control and advanced control techniques for large structures.

CONTROL OF LARGE SPACE STRUCTURES

Figure A-3 illustrates several spacecraft applications having varying requirements for attitude control. The "Advanced Communications Satellite" has substantial separation between structural frequencies and the control bandwidth, primarily because its staring application and pointing accuracy do not require wide bandwidth control. On the other hand, the "Large Electro-Optical Spacecraft" depicted in the figure has very rapid attitude maneuver and tight pointing accuracy requirements, necessitating an effective control bandwidth that contains many structural bending frequencies. Also, this spacecraft requires active figure control, distributed structural actuators, and active structural damping in order to meet its pointing accuracy and structural vibration settling time requirements. Several large antenna spacecraft (radar and radiometers) currently under study, also have requirements for this advanced control technology.

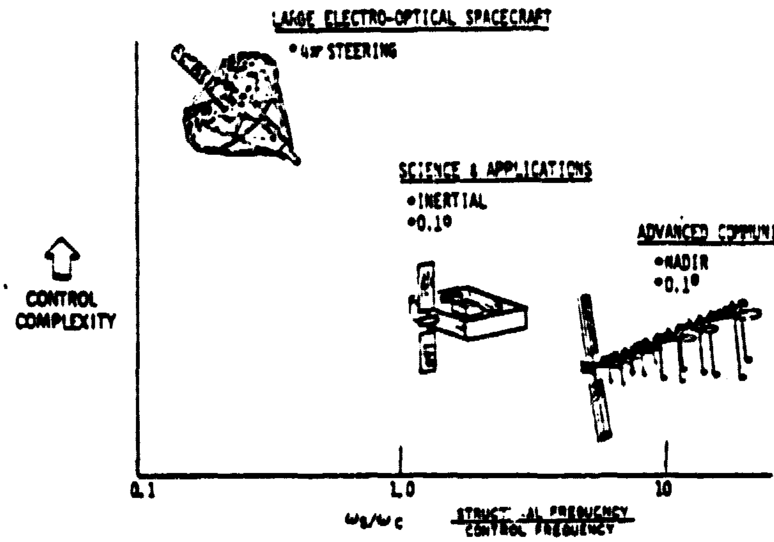
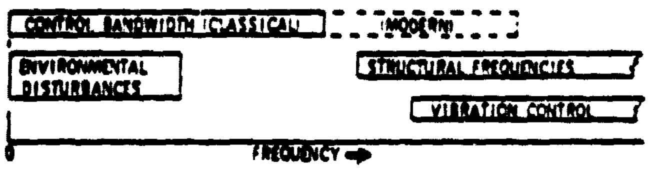


Figure A-3. Control of Large Structures

The modern control theory offers considerable promise for improving speed of response and control accuracy in large flexible systems (as depicted in Figure A-4). The effective bandwidth of these controllers can substantially overlap the structural bending frequencies and can provide active bending control and structural damping.

- MODERN CONTROLLERS—PROVIDE FASTER, MORE ACCURATE CONTROL



- NUMBER OF MODES TO CONTROL—CLUSTERED MODES
- ACTIVE VERSUS PASSIVE STRUCTURAL DAMPING
- CONFIRMATION OF DYNAMIC MODELS
- SENSITIVITY TO MODEL ERRORS—GENERAL MODEL & COEFFICIENTS
- SYSTEM IDENTIFICATION PROBLEM—ACCURACY, ADAPTIVE CONTROL FOR TIME-VARYING PARAMETERS
- STATE ESTIMATION
- DISTRIBUTED SENSORS & ACTUATORS VS. CENTRALIZED—NUMBER & LOCATION CRITERIA
- CONTROL SPILLOVER AND SUPPRESSION TECHNIQUES
- VIBRATION SUPPRESSION
- FIGURE (SHAPE) CONTROL—MAINTAIN ALIGNMENT IN PRESENCE OF ENVIRONMENTAL (THERMAL, ETC.), MANEUVER, AND ON-BOARD DISTURBANCE
- FLEX. STRUCTURE CONTROL WITH ON/OFF CONTROLLERS
- DISTURBANCE-TOLERANT CONTROLLERS
- FAIL SAFE

Figure A-4. Control of LSS—Issues

Modern controllers (Figure A-4) generally employ a truncated model of the system dynamics within the controller and, hence, are concerned with the issues of: how many modes to actively control (particularly in systems with closely spaced or clustered vibrational frequencies), and how much damping should be provided by the active controller versus passive structural damping techniques. Also, these controllers are relatively sensitive to errors in the dynamic models, thereby necessitating higher model accuracy than in controllers of the past. The mathematics for "system identification" have evolved and are beginning to see more application in ground testing and aircraft. Some spacecraft control situations with time-varying parameters will necessitate the real time on-board adaptive updating of system models.

State estimation theory has been practiced for some time; however, new problems are anticipated in the use of higher-order state estimators and their use in lowly damped dynamic systems with higher frequencies.

Distributed sensors and actuators offer promise of substantially improving active structural control systems. The distributed sensors can potentially improve the observability of higher-order dynamics and the distributed actuators can potentially locate the control forces to better control the structural dynamics. Preferred criteria for selecting the number and location of these control elements is an area of concern.

With actively controlled structural dynamic modes, considerably more high frequency harmonic content is present to excite the higher-order uncontrolled modes (spillover problem). Preferred techniques for spillover suppression are of concern.

Active figure (shape) control is required in some of the anticipated LSS applications. In some instances, new classes of structural sensors and actuators will require development and testing. Some of these figure control actuators generate very small forces and, hence, their performance can only be rigorously proven during space flight.

Current research has emphasized the use of linear effectors for control of LSS. The use of bi-state effectors (such as on/off RCS control) to control flexible body dynamics is an area warranting considerably more research.

Space construction and other space operations involving the motion of large elements relative to each other can produce appreciable control disturbances. Predictive, disturbance-tolerant controllers can be used to minimize the disturbing effects of those operations.

Failures that occur in modern control systems, which are employing large forces and power for active structural damping, can create unstable situations with destructive potential. Rapid failure detection and system reconfiguration are necessary to regain stability and prevent catastrophic results.

LSS Control with Orbiter Issues

The control of LSS attached to the orbiter, such as would be encountered during space construction, impose some additional issues (see Figure A-5). During space construction a considerable amount of mass is removed from the orbiter payload bay and redistributed to the vehicle under construction. This results in time-varying forces and torques on the system. Also, the moments of inertia and aerodynamic areas can change appreciably, thereby causing substantial

- GRAVITY-GRADIENT FREE-DRIFT MODES FOR SPACE CONSTRUCTION—ACCOMMODATE TIME-VARYING INERTIAS & DISTURBANCE TORQUES
- ORBITER RCS CONTROL AUTHORITY
- LSS DYNAMIC INTERACTION WITH ORBITER AUTOPILOT
- MINIMIZE DYNAMIC DISTURBANCES AT CONSTRUCTION SITE

Figure A-5. Control of LSS with Orbiter—Issues

changes in the environmental disturbance torques (primarily gravity gradient) acting on the system. Rockwell has proposed the use of gravity-gradient stabilized free-drift attitude modes for gross attitude control during these periods of construction. Attitude dynamic simulation has shown the feasibility of the approach. The stable gravity-gradient free-drift attitude mode is illustrated in Figure A-6. Space construction can be simulated during the boom experiment through the extension and retraction of the boom, and by gimbaling the boom so as to simulate the mass shifts associated with space construction.

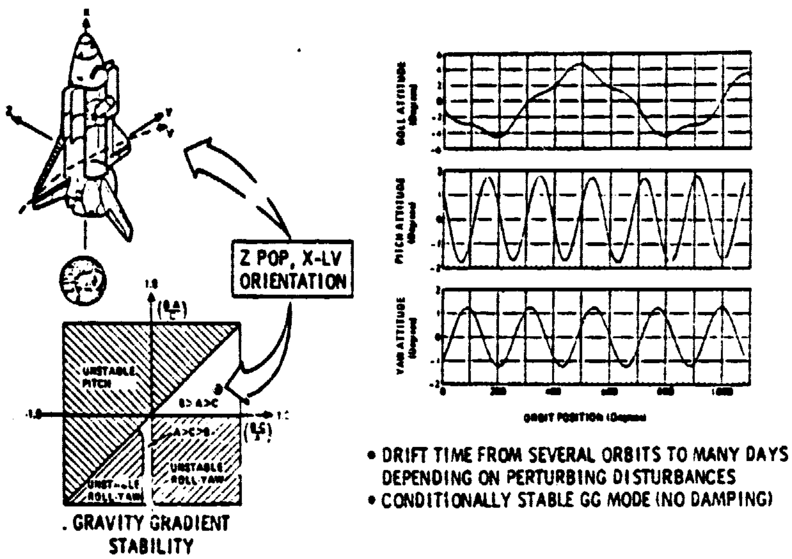


Figure A-6. Stable Gravity-Gradient Free-Drift Attitude Mode

The orbiter vernier RCS does not have torque couples and, hence, its control authority changes as the mass center moves during space construction or appendage deployment. The issue is addressed in subsequent paragraphs.

Large flexible structure attached to the orbiter has the potential to interact with the orbiter RCS control in an unstable manner. Research and experimentation with this issue can be addressed in the Precision Deployable Boom Experiment (PDBE).

Delicate construction operations can necessitate that dynamic disturbances at the construction site be minimized. The effects of various disturbances on construction operations can be verified in the experiment.

Control of LSS Experiments

Figure A-7 illustrates some of the "control of LSS" experiments that can be accomplished with the PDBE. Virtually all the issues discussed above can be addressed in a meaningful way. The PDBE may be visualized as a laboratory to permit the verification and comparison of a broad variety of controller software and hardware. A variety of structural dynamics can be achieved by distributing masses at various locations on the boom. Potential sensors for dynamic instrumentation and control include strain gauges, accelerometers,

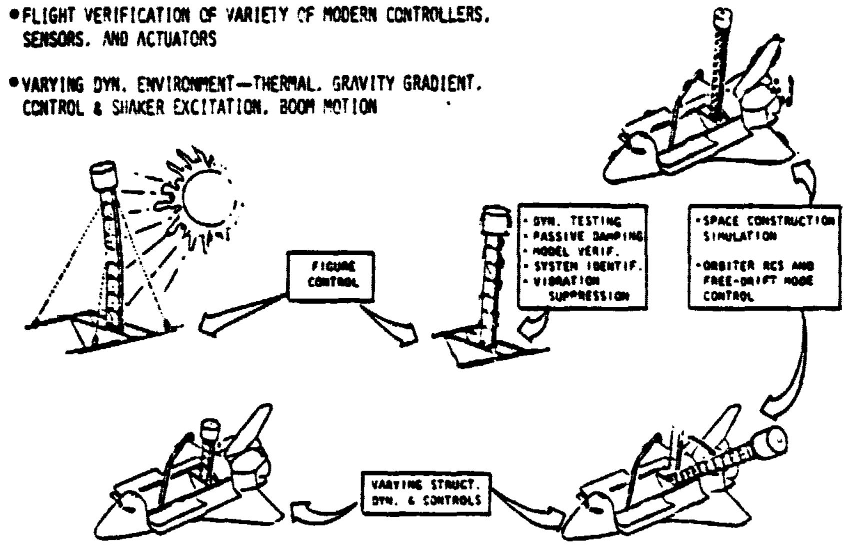


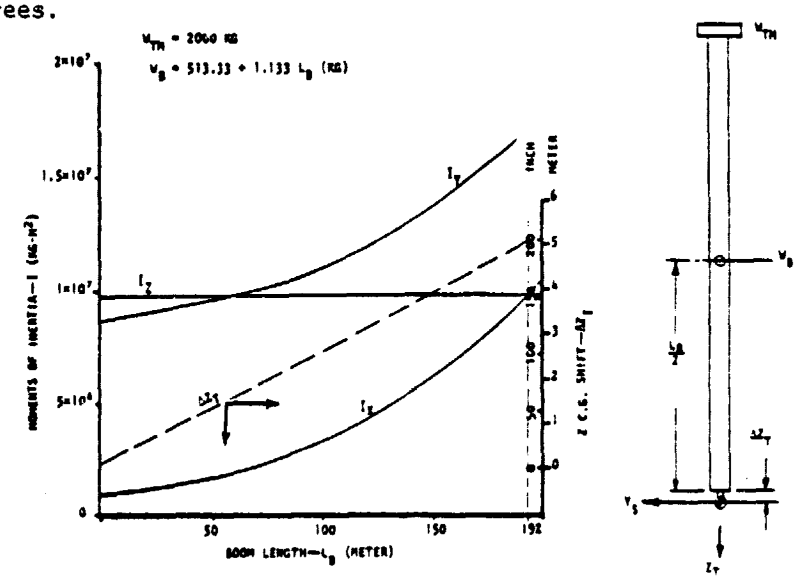
Figure A-7. Potential Control of LSS Experiments

gyros, solar and stellar sensors, and special figure control sensors. Control effectors may include momentum wheels, control moment gyros, cold-gas thrusters, and figure control activators. A computer of relatively large capacity will be required for experiment control.

Experiment Boom Sizing

One criterion for the experiment boom sizing is to achieve sufficient mass and distance that space construction operations can be simulated. To accomplish this, major changes in the moments of inertia (and related gravity-gradient torques) must take place. Figures A-8 and A-9 illustrate that shifts between principal axes of inertia can occur if a boom with tip mass of 2000 kg is extended past 60 m and that the same thing happens for a gimbal rotation beyond approximately 48 degrees.

Figure A-8. Boom Sizing—Inertia and C.G. Shifts Versus Boom Length



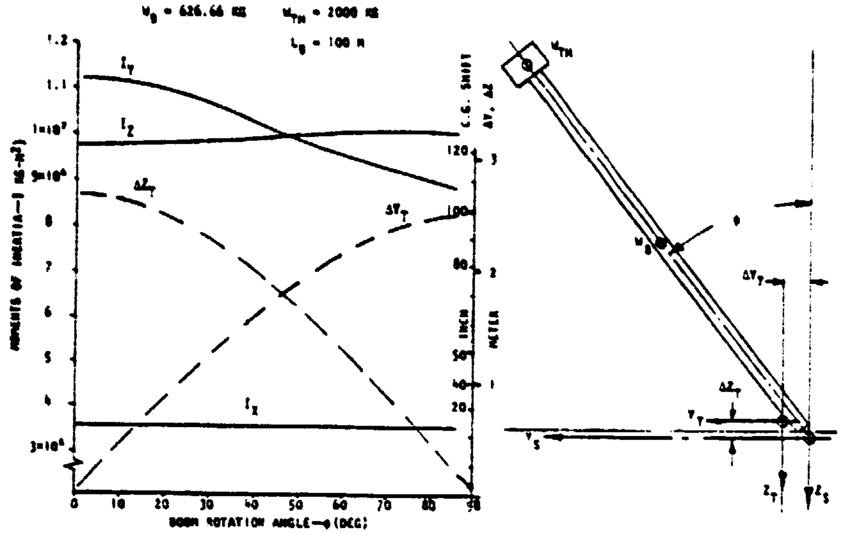


Figure A-9. Inertia and C.G. Shifts Vs. Boom Rotation (ɸ)

Figure 10 presents some parametric boom structural sizing data. First mode bending frequencies in the range of 0.01 to 0.1 Hz are reasonably representative of LSS currently under investigation. Low frequencies are desirable to permit crew monitoring, whereas higher frequencies are desirable to stay well above the orbiter VRCS limit cycle pulsing frequencies that are in the order of 0.01 Hz. It is concluded that a 100-m boom with 2000 kg tip mass can provide a reasonable frequency range within the diameter constraints of the orbiter payload bay, and with reasonable total experiment mass. No attempt to optimize the experiment size has been made.

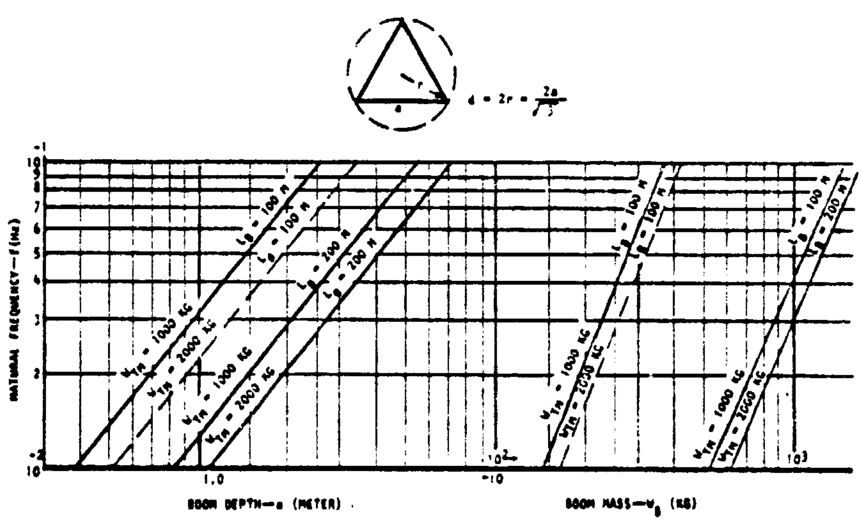


Figure A-10. Boom Sizing

Orbiter VRCS Control Authority

As the experiment boom is deployed, the center of mass of the system will shift and the question of maintaining VRCS control authority becomes an issue. The roll axis is the axis of concern. Figures A-11, A-12, and A-13 present the roll control torques as a function of center-of-mass shift and boom gimbal angle. The c.g. shift is approximately 110 inches. It may be seen from these data that the VRCS control torques are diminished, but that a combination of jets is available which will provide adequate control torques.

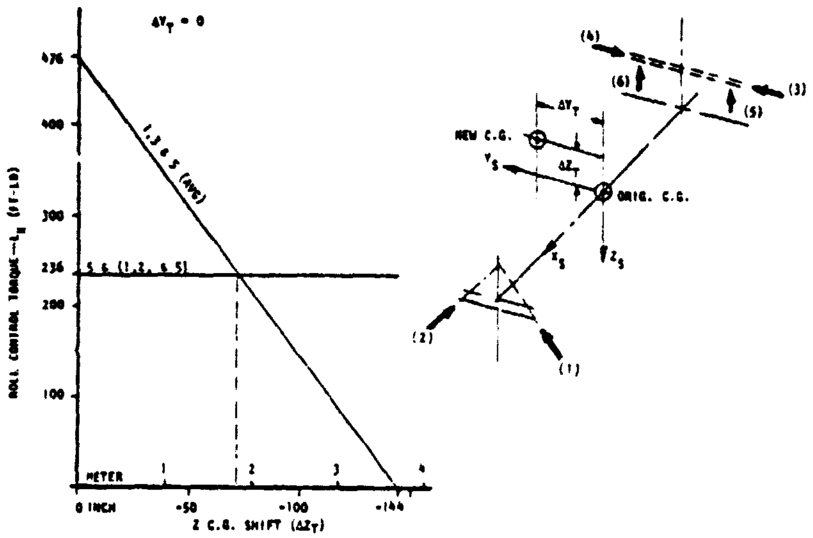


Figure A-11. Roll Control Authority Vs. Z C.G. Shift

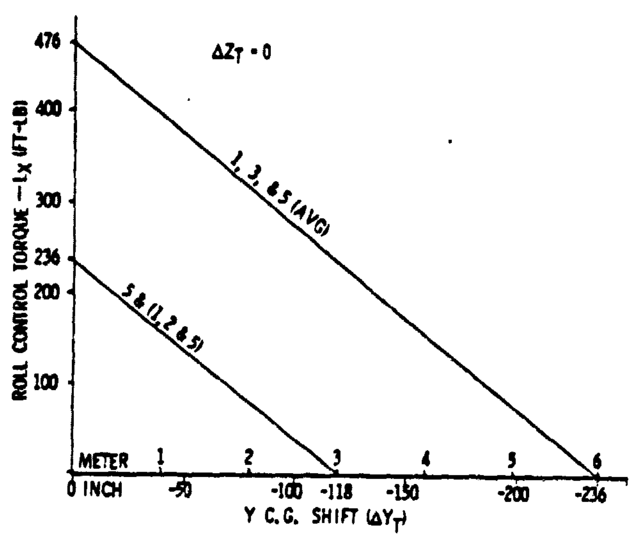


Figure A-12. Roll Control Authority Vs. Y C.G. Shift

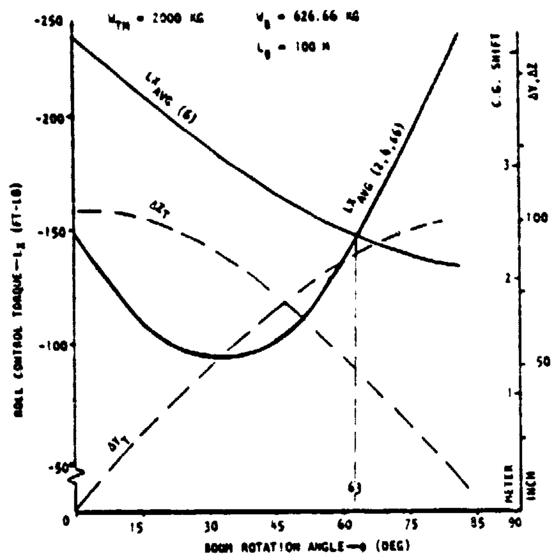


Figure A-13. Roll Control Torque and C.G. Shifts Vs. Boom Rotation (φ)

CONCLUSIONS (see Figure A-14)

It is concluded that the PDBE appears capable of containing, in some reasonable way, the issues and concerns of the LSS controls technical community. A boom size in the order of 100 m and 2000 kg can satisfy the experiment requirements. The simulation of space construction operations dominates in the boom sizing criteria. Other "control of LSS" issues can be satisfied with a smaller experiment. The orbiter roll control authority with the VRCS is slightly diminished when the experiment is deployed, but adequate control torques are available. In order that the PBE have the greatest possible benefit to future technology development, the experiment must be closely aligned with precision structures and control technology development programs, and should carefully embody the specific technology requirements imposed by future spacecraft programs. The controls community would welcome the opportunity afforded by the PDBE to verify their advanced concepts for control of large flexible space systems.

- EXPERIMENT CAN POTENTIALLY ADDRESS ALL MAJOR CONTROLS ISSUES
- BOOM SIZE OF APPROXIMATELY 100 m CAN SATISFY OBJECTIVES
- ORBITER VERNIER RCS CONTROL AUTHORITY CHALLENGED WITH LARGE EXPERIMENT (SUBSTANTIAL CROSS-COUPLING)
- EXPERIMENT DEFINITION MUST CAREFULLY CONSIDER FUTURE APPLICATIONS TO PROVIDE GREATEST TECHNOLOGY BENEFITS

Figure A-14. Conclusions